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An Assessment of

Development and Production Potential of Federal Coal Leases

Volume II—Working Papers

Part H: Criteria for Determining Viable Mining Properties on Existing Federal Coal Leases in the Western United States

October 1982

CONGRESS OF THE UNITED STATES
Office of Technology Assessment
Washington, D. C. 20510

Preface

This volume contains papers written for OTA to assist in preparation of the report *An Assessment of Development and Production Potential of Federal Coal Leases.* OTA does not endorse these papers. In several instances, the OTA report reaches somewhat different conclusions because of additional information which was obtained later. These papers, however, may prove valuable for readers needing more detailed or specific information than could be accommodated in the final assessment report, and are being made available for such purposes.

OTA WORKING PAPER H

CRITERIA FOR DETERMINING VIABLE MINING PROPERTIES ON EXISTING FEDERAL COAL LEASES IN THE WESTERN UNITED STATES

FINAL REPORT

prepared for

OFFICE OF TECHNOLOGY ASSESSMENT
Congress of the United States
Washington, D. C. 20510

by the

Colorado School of Mines Research Institute
Golden, Colorado

March, 1980

This is an OTA Working Paper used in preparation of OTA's final report on federal coal leasing. The findings and conclusions of this report are those of the author and do not necessarily represent the views of OTA or the Technology Assessment Board. This report has not been reviewed or approved by the Technology Assessment Board.

PREFACE

This report was prepared by the Colorado School of Mines Research Institute for the Office of Technology Assessment for its study of coal leases on Federal lands mandated by Section 10 of the Federal Coal Leasing Amendments Act of 1976, Public Law 94-377.

This report describes coal reserves and mining conditions for coal regions in seven western states with significant amounts of Federal coal land under lease: Colorado, Montana, New Mexico, North Dakota, Oklahoma, Utah and Wyoming. For each region, a profile of surface and underground mining operations that are representative of the region are developed and regional trends are identified. These summaries were used by OTA's coal leasing task force held in Colorado, New Mexico, Oklahoma, Utah and Wyoming. A special section on small "lump coal" mines in Utah was contributed by Dr. Helmutt Doelling of the Utah Geological and Mineral Survey. These profiles were used by OTA in its analysis of the potential for development of currently nonproducing Federal leases in these states.

OTA's final report to the Congress, An Assessment of Development and Production Potential of Federal Coal Leases was issued in December 1981.

OTA working papers used in the preparation of OTA reports are made available to the public after delivery of the final report to the Congress. Any opinions, findings, conclusions or recommendations expressed in these working papers are those of the authors and do not necessarily reflect the views of the Office of Technology Assessment, the Technology Assessment Board, or the United States Congress.

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EXECUTIVE SUMMARY

CONVENTIONAL MINE PROFILES
FOR COAL PRODUCING REGIONS IN THE WEST: 1980-1990

To assist OTA in fulfilling its Congressional mandate of assessing the present and potential value of existing federal coal leases, a set of technical criteria have been developed that describe (1) representative conventional coal mining operations, (2) general mining conditions, and (3) typical coal characteristics for both surface and underground operations in the seven states--Colorado, Montana, New Mexico, Utah, Wyoming, North Dakota and Oklahoma--in which the majority of federal coal leases lie.

The conventional mine profiles developed for the 1980-1990 timeframe include coal rank, quality, and thickness parameters, minimum leasehold and recoverable reserve requirements, mining technologies, and mine capacities that are likely to be representative of viable mining operations in given coal mining regions. Likely markets for the leased coal have also been identified.

The mine profiles provide guidance as to the nature and characteristics of mine developments in the 1980's, given individual property and coal characteristics. The mine profiles, for example, provide guidance concerning (1) the production level that might be anticipated from an undeveloped lease; (2) the potential market and end-use of the leased coal; and (3) the labor and transportation requirements associated with development.

The mine profiles included in this report are organized by state, region, and coal field. Each state section begins with a general statement concerning such factors as coal resources and reserves, mining methods, mine size, coal utilization, potential for expansion, and coal characteristics. For each region, and for principal coal fields within each region, such development-related factors as current and past production levels, regional trends in mining methods, and mine size are discussed.

Key characteristics of the mine profiles, as well as a summary of how the technical criteria were determined and the sources of information from which the criteria were derived, are summarized in Table I. Mine profile data were compiled and interpreted using a variety of government and industry documents, such as the Keystone Coal Industry Manual, mine plans, and coal newsletters. In addition, coal industry representatives and officials from the Colorado state office of the Bureau of Land Management, the Denver field office of the Department of Energy (Energy Information Administration) the U.S. Geological Survey Conservation Division, and coal geologists with the state geological surveys of Colorado, Montana, Utah, and Wyoming, provided technical information.

Certain mining trends in Western coal production can be drawn from a review of the mine models. The long-term trend in such states as Colorado, Utah, and Wyoming is toward increased production of underground-mined steam coal, mines in some areas extending to deep beds underlying currently surface-mined coal. Little or no growth is projected for metallurgical-grade (coking) coal production from 1980 to 1990: essentially all metallurgical coal is extracted in underground operations.

Most of the new mines that have opened in the Rocky Mountain Region in the past five years have been large surface operations with annual production levels of 0.5 - 10 million tons, extracting subbituminous coal in single beds which range in thickness from 10 to 100 feet. Most of the very large new surface mines are located in the Northern Great Plains province (Wyoming and Montana), whereas lignite production is centered in western North Dakota. Medium to large single-bed surface mines have opened in the Rocky Mountain coal province, subbituminous steam coal operations have increased in the San Juan River region, and bituminous steam coal production has expanded in the Green River region.

Likely production trends by state for the 1980-1990 timeframe are summarized as follows:

COLORADO

Denver coal region: trend is toward medium-sized (0.5 to 0.9 mtpy) surface coal mines producing subbituminous steam coal.

Green River coal region: trend is toward a decrease in surface-mined coal and an increase in underground-mined bituminous steam coal, mostly from mines in the 0.5 to 1.9 mtpy range.

North Park coal region: trend is toward surface mines producing less than 1.0 mtpy.

Raton Mesa coal region: trend is toward underground mines in the 0.5 to 0.9 mtpy range that will mine both steam and coking coal; and toward small surface steam coal mines (less than 0.5 mtpy).

San Juan River coal region: continuation of small (less than 0.1 mtpy) underground steam/domestic coal mines in the Durango area; Larger mines may open if and when a railroad is constructed into the Four Corners area.

Uinta coal region: trend is toward large surface bituminous steam coal mines in the 1.0 to 2.9 mtpy range; and large underground bituminous steam and coking coal mines in the 0.4 (or less) to 1.9 mtpy range.

WYOMING

Green River coal region: trend is toward medium to large (0.5 to 6.8 mtpy) surface mines to produce both subbituminous and bituminous steam coal; and toward large underground mines to produce 1 to 2 mtpy of subbituminous and bituminous steam coal.

Ham's Fork coal region: trend is toward surface mines in the 1 to 5 mtpy category to produce subbituminous and bituminous steam coal.

Hanna coal field: trend is toward surface mines in the 1 to 5 mtpy range, and underground mines in the 0.6 to 1.5 mtpy range, both categories to produce subbituminous steam coal.

Powder River coal region: trend in this, the most important coal-producing basin in Wyoming, is toward large surface mines, mostly in the 5 to 15 mtpy range; a few mines will be in the 15 to 20-plus mtpy range; all will produce subbituminous steam coal.

MONTANA

Fort Union coal region, northern Powder River basin area: trend is toward large surface subbituminous coal mines in the 5 to 20 mtpy range.

Fort Union coal region, Williston basin area: trend is toward large mines (1 mtpy or more) that will surface-mine lignite for use in steam-electric power plants and, possibly, for coal gasification.

NEW MEXICO

San Juan River coal region, San Juan basin fields: trend is mainly toward surface mining of subbituminous steam coal, primarily in the 2.0 to 3.9 mtpy range, with some smaller mines. Some mines will be in the 3.0 to 5.9 mtpy range. A smaller amount of underground mining (2 mtpy) can also be anticipated.

Raton Mesa coal region, Raton field: little or no growth is anticipated during the next 5 to 10 years.

NORTH DAKOTA

Fort Union coal region, Williston basin area: trend is toward surface mines in the 1 to 6 mtpy range to provide lignite to power plants. Those mines planned to supply lignite feedstock to proposed coal gasification plants are expected to produce 12 to 14 mtpy.

OKLAHOMA

Interior coal province, Western region (southern part): trend is toward small surface mines with design capacities in the 0.2 to 0.4 mtpy range, to mine bituminous steam and coking coal.

UTAH

Uinta coal region, Book Cliffs field: trend is toward relatively large (0.2 to 1.0-plus mtpy) underground mines to produce bituminous steam coal.

Uinta coal region, Wasatch Plateau field: trend is essentially the same as for Book Cliffs field.

Uinta coal region, Emery field: trend is toward relatively large (0.5 to 1.0-plus mtpy) underground and surface mines to produce bituminous steam coal. Development may be hampered because no rail line serves the field.

Southwestern Utah coal region, Kaiparowits Plateau field: trend is toward relatively large (0.5 to 1.0-plus mtpy) underground mines to produce subbituminous and bituminous steam coal. Development will be retarded until a rail line is constructed into the region.

Southwestern Utah coal region, Alton field: trend is toward large (10-plus mtpy) surface mines to furnish subbituminous steam coal to planned new electric power plants in southwestern Utah and Nevada. Coal may be transported via a slurry pipeline.

The conventional mine profiles described in this report are generalized accounts of conventional development expected in the Western federal coal lease areas. As such, they can assist in assessing the development prospects of nonproducing lease tracts. It should be noted that some factors considered only generally in the mine models, if at all, would probably receive more attention by prudent developers in making site-specific development decisions. These factors include (1) the lessee's willingness, financial resources, and mining experience to develop the property; (2) joint ventures with contiguous lessees; (3) the likelihood of development on immediate federal, state, and private lands; and (4) state and federal laws and policies governing mine and mine-related operations.

KEY CHARACTERISTICS OF MINE PROFILES

CHARACTERISTIC	METHOD OF DETERMINATION	PRINCIPAL DATA SOURCES
I. Representative Mining Operations Criteria		
1. Coal Rank	As stated in available literature, or derived from coal analysis data, using ASTM standards.	Keystone Manual, State geological survey publications.
2. Minimum Leasehold Requirement (Surface and Underground Operations)	Divided minimum recoverable reserves estimate (in tons) by number of tons of coal per acre.	Keystone Manual, published literature, CSMRI files, discussions with government and industry experts.
3. Minimum Recoverable Reserves	Multiplied design capacity of mine (tons/year) times estimated life of mine.	Sources as above.
4. Mine Life	Extrapolated from estimates of the expected life of steam electric powerplants, for areas with favorable steam coal quality characteristics, and the amortization period of mine capitalization.	Sources as above.
5. Design Capacity (Surface and Underground Operations)	Analysis of trends in conventional and new mine developments, including mine-mouth powerplants.	Mine plans, EIS's, unpublished government documents, and sources as above.
6. Mining Technology	Review of literature plus professional judgment of industry and government specialists.	Sources as above.
7. Coal Price/FOB Price	Summary and projection of published and unpublished data.	Coal Outlook, DOE/EIA publications.
8. Capital Requirements	Review and analysis of published and unpublished data.	U.S. Geological Survey, Bureau of Mines, Bureau of Land Management, Department of Energy.

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KEY CHARACTERISTICS OF MINE PROFILES (Cont'd)

CHARACTERISTICS	METHOD OF DETERMINATION	PRINCIPAL DATA SOURCES
9. Labor Requirements	Review and analysis of published and unpublished data.	Mine plans, EIS's and EAR's, state publications and permit applications, discussions with industry experts.
10. Surface Equipment	Review and analysis of published and unpublished data.	Sources as above.
11. Proximity to Transportation/Common Transportation Mode	Review and analysis of published and unpublished data.	Colorado Energy Research Institute, various state and federal publications, consultation with industry and government experts.
12. Community Infrastructure Requirements	Review and analysis of published and unpublished data.	Mine plans, EIS's, state publications and permit applications, Colorado Energy Research Institute.
II. General Mining Conditions		
1. Structural Attitudes	Review of published data and maps.	Keystone Manual, state and federal publications, professional judgment.
2. Topographic Relief	Review of published data and maps.	Sources as above.
3. Maximum Overburden	Review of published data and maps.	Sources as above.
4. Market	Analysis of published and unpublished data.	Keystone Manual, state and federal publications, discussions with industry and government experts.

KEY CHARACTERISTICS OF MINE PROFILES (Cont'd)

CHARACTERISTICS	METHOD OF DETERMINATION	PRINCIPAL DATA SOURCES
III. Typical Coal Bed Characteristics		
1. Analysis, as-received (Rank, sulfur content, heating, values, volatile matter, ash content.)	Analysis of published data.	Keystone Manual, state and federal publications, mine plans.
2. Coal Thickness	Analysis of published data.	Same as above.
3. Mining Problems	Review of published data.	Keystone Manual, state and federal publications, contractor's regional experience.

SUMMARY OF CONVENTIONAL COAL MINE DEVELOPMENT MODELS, WESTERN U.S.

STATE COAL REGION (COAL FIELD)	Coal Rank[1] (Formation)	Coal Quality Range (as-received) Moisture (%)	Volatile Matter (%)	Ash (%)	Sulfur (%)	Heating Value (Btu/lb)	Coal Thickness (ft)	Minimum[2] Leasehold Required (acres)	Minimum Recoverable Reserves (tons x 10⁶)	Mine Life (yr)	Design[2] Capacity (tons x 10⁶/yr)	Common[4] Technology	Likely[5] Markets
COLORADO													
Denver Region	SB (Laramie)	13-35	27-45	4-20	0.2-1.1	6,200-10,800	3-20	75-500	2	20-30	1.2(U)	S: Conv.; U: Shaft	S-EG (Local, Municipal), Conversion?
	L (Denver)	26-40	19-43	10-45	0.2-0.6	3,600-6,800	10-55	75-500	2	20-30	1.2(U)	S: Conv.; U: Shaft	S-EG (Local, Municipal), Conversion?
Green River Region	HVBC (Mesaverde)	6-17	34-39	3-20	0.3-1.8	9,800-12,600	3-20	1,300(S), 600(U)	20(S), 6(U)	20-30	1-3(S),0.3-2(U)	S: Conv.; U: Drift or Slope	S-EG (Colorado, Midwest)
	SB (Lance)	20-22	--	4-7	0.5-0.7	9,600-9,700	7-10	1,300(S), 600(U)	20(S), 6(U)	20-30	1-3(S),0.3-2(U)	S: Conv.; U: Drift or Slope	S-EG (Colorado, Midwest)
	SB (Ft. Union)	21-23	--	4-8	0.2-0.4	8,300-8,700	7-40	1,300(S), 600(U)	20(S), 6(U)	20-30	1-3(S),0.3-2(U)	S: Conv.; U: Drift or Slope	S-EG (Colorado, Midwest)
	SB? (Wasatch)	--	--	--	--	--	2-20	1,300(S), 600(U)	20(S), 6(U)	20-30	1-3(S),0.3-2(U)	S: Conv.; U: Drift or Slope	S-EG (Colorado, Midwest)
North Park Region	SB (Coalmont)	12-20	27-37	2-19	0.2-1.0	6,300-11,300	35-60	50	4	Several	0.2-2.0	S: Conv.	S-EG (Colorado, Illinois)
Raton Mesa Region	HVB-MVB (Raton)	2-5	34-40	5-16	0.4-1.1	10,200-13,900	7-10	1,100	10	20-30	0.5-0.9	S: Conv.; U: Conv. or LW	M (Local, Eastern U.S.), S-EG?
	HVB-MVB (Vermejo)	2-10	32-39	7-22	0.5-1.3	11,000-13,500	7-10	1,100	10	20-30	0.5-0.9	S: Conv.; U: Conv. or LW	M (Local, Eastern U.S.), S-EG?
San Juan River Region	SB-B (Fruitland)	1-16	21-47	7-27	0.5-0.9	9,400-12,100	1-40	20-2,200	1-20	20-30	0.1-1.0	S: Conv.; U: Conv.	S-EG, M (Local)
	B (Menefee)	2-11	36-42	3-17	0.6-1.3	10,800-14,700	1-40	20-2,200	1-20	20-30	0.1-1.0	S: Conv., U: Conv.	S-EG, M (Local)
	B (Dakota)	3-14	33-36	6-13	0.5-1.1	10,100-13,400	1-40	20-2,200	1-20	20-30	0.1-1.0	S: Conv., U: Conv.	S-EG, M (Local)
Uinta Region													
(Book Cliffs Field)	HVBC-HVBB	3-14	30-35	5-23	0.4-1.7	9,800-13,600	6-9	300	8-9	15-30+	0.4-3(S),0.2-2(U)	S: Conv.; U: Conv. or LW	S-EG (West, Midwest, South U.S.)
(Carbondale Field)	HVBA-AN	1-4	22-39	3-10	0.3-1.5	12,500-15,200	1-10	300	8-9	15-30+	0.4-3(S),0.2-2(U)	S: Conv.; U: Conv. or LW	M (Western U.S., Asia)
(Crested Butte Field)	HVBC-AN	2-13	--	3-9	0.4-1.9	11,400-14,200	2-14	300	8-9	15-30+	0.4-3(S),0.2-2(U)	S: Conv., U: Conv. or LW	M (Western U.S., Asia)
(Danforth Hills Field)	HVBC	9-15	--	2-10	0.3-1.4	10,100-12,000	7-20+	300	8-9	15-30+	0.4-3(S),0.2-2(U)	S: Conv., U: Conv. or LW	M (Western U.S., Asia)
(Grand Hogback Field)	HVBC-HVBA	4-5	37-40	6-10	0.6-0.7	12,100-12,600	3-18+	300	8-9	15-30+	0.4-3(S),0.2-2(U)	S: Conv., U: Conv. or LW	M (Western U.S., Asia)
(Grand Mesa Field)	SB-HVBC	3-20	30-35	2-18	0.5-2.2	8,300-13,500	4-14	300	8-9	15-30+	0.4-3(S),0.2-2(U)	S: Conv., U: Conv. or LW	M (Western U.S., Asia)
(Lower White River Field)	HVBC	11-14	--	4-9	0.4-0.5	10,800-11,200	8-12+	300	8-9	15-30+	0.4-3(S),0.2-2(U)	S: Conv., U: Conv. or LW	M (Western U.S., Asia)
(Somerset Field)	HVBC-HVBB	3-14	35-38	3-11	0.5-0.8	10,000-13,500	7-30	300	8-9				
MONTANA													
Fort Union Region													
(Northern Powder River Area)	L-SB (Fort Union)	13-42	21-40	4-11	0.1-1.6	6,500-9,900	4-80	200-2,000	20-30	20-30	1-20	S: Conv.	S-EG (Midwest), Conversion?
(Williston Basin Area)	L (Fort Union)	30-40	--	6-11	0.3-0.9	6,000-7,500	10-50	300-2,000	20-30	20-30	0.3-1.0	S: Conv.	S-EG (Midwest), Gasification
NEW MEXICO													
Raton Field	HVBB-HVBA (Raton)	6	36	9-14	0.6	14,300	6-13	1,000(S),2,000(U)	20	20-30	1	S: Conv.; U: Conv.	M (Western U.S.)
San Juan Basin	SB-HVBB (Mesaverde)	4-15	25-39	5-24	0.5-2.0	8,900-13,000	3-50	300-2,000	20-30	20-30	2-4	S: Conv.	S-EG (Western U.S.), Gasification
NORTH DAKOTA													
Fort Union Region (Williston Basin Area)	L (Fort Union)	36-44	24-30	5-8	0.2-1.4	5,900-7,500	2-37	200-3,000	20-30	20-30	1+	S: Conv.	S-EG (N. Great Plains)
OKLAHOMA													
Western Region -- Interior Coal Province (Southern Part)													
Arkoma Basin	HVBC-LVB	1-5	20-37	4-23	2.0-5.0	11,700-14,400	1-7	50-100	0.2	20-30	0.2-1.5	S: Conv.	S-EG (Midwest), M, Manufacturing
Northeastern Shelf	HVBC-HVBA	1-7	30-36	5-19	1.0-3.0	11,600-14,100	1-5	50-100	0.2	20-30	0.2-1.5	S: Conv.	S-EG (Midwest), M, Manufacturing
UTAH													
Uinta Region													
(Book Cliffs Field)	HVBC-HVBB	4-7	38-45	6-7	0.4-1.0	12,500-13,000	4-16	3,000-4,000	10-30	25-30	0.2-1.0+	U: Conv., LW	S-EG (Utah, Midwest)
(Wasatch Plateau Field)	HVBC-HVBB	5-7	41-42	6-7	0.6	12,200-12,700	4-24	2,000-3,000	10-30	20-30	0.2-1.0+	U: Conv.	S-EG (Utah, Midwest)
(Emery Field)	B	7-8	38-41	9-20	0.5-2.5	11,400-12,300	4-12	2,500?	20-30	25-30	0.5-1.0	U: Conv., S:?	S-EG (Utah, Midwest, South?)
Southwestern Utah Region													
(Kaiparowits Field)	SB-HVBA	10-20	43-45	8-14	0.8-1.3	11,200-12,400	3-25	5,000-10,000	70-150	25-30	0.5-1.0	U: Conv., LW?	S-EG (Region)
(Alton Field)	SB	17	33	9	1.1	9,600	12-16	8,000-10,000	100-200	25	10-11	S: Conv.	S-EG (Region)
WYOMING													
Green River Region	SB-B	8-23	29-39	2-17	0.4-5.0	7,000-12,500	6-50	300+	20-100	20-30	0.5-6.8	S: Conv.	S-EG (Northwest, Midwest, South)
Ham's Fork Region	SB-B	3-21	34-40	3-9	0.2-1.1	9,500-12,900	5-110	300+	20+	20-30	1.5-4.0	S: Conv.	S-EG (Western U.S.)
Hanna Field	SB	10-37	34-41	5-15	0.4-0.9	9,300-11,400	10-36	300+	20-30	20-30	0.3-1.5	S: Conv.; UG: LW?	S-EG (Midwest)
Powder River Basin	L-SB	20-44	27-49	2-22	0.1-3.0	6,500-10,410	10-220	200-2,000+	1-100	20-30	0.02-33	S: Conv.	S-EG (Wyoming, Midwest)

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[1] L = Lignite; SB = Subbituminous; B = Bituminous; HVB = High-Volatile Bituminous (C,B,A); MVB = Medium-Volatile Bituminous; LVB = Low-Volatile Bituminous; AN = Anthracite.

[2] S = Surface; U = Underground.

[3] Conv. = Conventional; LW = Longwall.

[4] S-EG = Steam-Electric Generation; M = Metallurgical.

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INTRODUCTION

The Federal Coal Leasing Amendments Act of 1976 (Section 10 of Public Law 94-377) directs the Office of Technology Assessment to conduct a study of all Federal coal leases issued under the Mineral Leasing Act of 1920. One of the chief tasks assigned to OTA is to determine the present and potential value of all Federal coal leases. A subtask is the determination of the development potential of nonproducing Federal coal leases, including anticipated production. The "development potential" in this instance is considered to be a "measure of value" of these leases.

STATEMENT OF WORK

The contractor that performed the work contained in this report established a set of criteria that is believed to be essential for determining whether or not viable mining operations might be established on existing nonproducing Federal coal leases. The area considered includes coal-bearing regions located in certain Rocky Mountain States (Colorado, Montana, New Mexico, North Dakota, Utah, and Wyoming -- comprising the Rocky Mountain and Northern Great Plains coal provinces), together with Oklahoma (located in the Western region of the Interior coal province).

Within the numerous coal-bearing regions that are located in these several states and within which nonproducing Federal coal leases exist, the contractor discriminated general areas that exhibit similar mining and coal characteristics (e.g., type of mining, geologic factors, coal rank and quality, production levels, and end use). Maps displaying these discrete "mining areas", in varying degrees of detail, are included with the data for each state.

Criteria were established by which surface and(or) underground coal mines in each mining area (which may range from a large coal region down to a small coal-producing district) might be characterized. A number of criteria were developed under three basic categories: (1) representative mining operations, (2) general mining conditions, and (3) typical coal bed characteristics.

Conventional mine models were developed for each area for the 1980-1990 time frame. Available literature, together with consultation with recognized experts in both government and industry, were utilized by the contractor in developing these models. Technical considerations that might be employed by prudent operators to make "go/no-go" decisions were emphasized. Legal/institutional issues were incorporated in a minor way, if at all, in this study.

USE OF MINE MODELS BY OTA

The various mine models established by the contractor are expected to be used by OTA in a variety of ways, including the following:

1. As a reference against which the various characteristics of a given property (e.g., size of lease, quality and depth of coal) and its development potential might be measured.
2. As a measure of the production level that might be anticipated or possible from a given lease.
3. As a measure of the potential market and end use of the type of coal presumed or known to be present within a given lease.
4. As an indication of labor and transportation requirements in order to better assess socioeconomic impacts in nearby communities.
5. As an indication of the feasibility of building coal conversion (gasification or liquefaction) plants in the vicinity.
6. As an indication of potential adverse environmental impacts in the general area.

It should be emphasized that these mine models are highly generalized and do not take into account the particular mining and marketing strategy of a specific leaseholder. A Western utility company lessee, for example, would probably have a different approach to development than would a large Eastern coal producer that already has established a strong market for steam coal in the Midwest. A lessee interested in developing a coal conversion ("synfuels") plant in the vicinity may require far more reserves than are contained within the lease tract in question, whereas a small producer supplying the local domestic coal market might well be able to make a reasonable profit by developing just the one lease, without requiring contiguous acreage in order to assemble a larger logical mining unit.

The mine models can be used, in some instances, to establish the relative value of a specific lease, compared to other leases in the mining area. However, a more realistic measure of the "present and potential value" of an undeveloped coal lease perhaps is equally or more dependent upon (1) the identity of the leaseholder (e.g., large or small coal company, independent, public utility, speculator), (2) the identity of the contiguous lessors and lessees, (3) existing mined land reclamation rules and regulations, (4) existing environmental restrictions (e.g., air, water quality), (5) current local and regional market conditions, and so on.

Again, the characteristics applied to each mine model will allow a "first cut" to be made as regards the "development potential" of a particular lease; however, considerable caution must be used when applying these models to existing "real world" situations.

CONTENT OF MINE MODELS

For each state included in this study, a general statement is made concerning such items as coal resources and reserves, mining methods, mine size, utilization, future potential, and coal characteristics.

For each region, and sometimes for each coal field, in which undeveloped Federal coal leases exist, a general statement is made regarding such factors as production, regional trends in mining methods and mine sizes, and utilization.

Each conventional mine development model is divided into three basic categories, with criteria generally considered important assigned to each category (e.g., Representative Mining Operations -- coal rank, minimum leasehold required, minimum recoverable reserves required, mine life, coal price, design capacity, mining technology, etc.).

The following publications and agencies were the main sources of information utilized by the contractor in assembling the coal data and establishing the mine models:

1. Keystone Coal Industry Manual (1979).
2. Industry publications (Coal Age, Coal Mining and Processing, Coal Outlook, Coal Daily, etc.).
3. U.S. Department of Energy Coal Development Monitoring System.
4. Colorado Energy Research Institute, Division of Mines, and Geological Survey.
5. Colorado School of Mines Research Institute.
6. Montana Bureau of Mines and Geology
7. New Mexico Bureau of Mines and Mineral Resources.
8. North Dakota Geological Survey.
9. Oklahoma Geological Survey.
10. Utah Geological and Mineral Survey.
11. Geological Survey of Wyoming.
12. Office of Utah State Science Advisor ("Utah Energy Resources").
13. Lake Powell Research Project (California State Department of Water Resources and State Energy Commission).
14. Missouri River Basin Commission ("Western Coal Planning Assistance Project," Resource and Land Investigations Program for Montana, North Dakota, and Wyoming, 1979).
15. Ozarks Regional Commission ("Final Report, Investigation of the Coal Reserves in the Ozarks Section of Oklahoma," 1974).
16. U.S. Geological Survey.

17. U.S. Department of the Interior (Final EIS's, Development of Coal in Central and Southern Utah; Final EIS, Proposed Federal Coal Leasing Program).

In Addition, conversations were held with individual experts from industry; the Colorado State Office of the U.S. Bureau of Land Management; the Denver Field Office of the U.S. Department of Energy/EIA; the Conservation Division, U.S. Geological Survey, Denver; and coal geologists with the State Geological Surveys in Colorado, Montana, Utah, and Wyoming.

KEY CHARACTERISTICS OF MINE MODELS

Characteristic	How Determined/Sources of Data
1. Coal Rank	Either from stated rank or derived rank from coal analysis data, using ASTM standards/Keystone Manual, State geological survey publications, contractor's files, etc.
2. Minimum Leasehold Required	Divided minimum recoverable reserves required (in tons) by number of tons of coal per acre (e.g., 10-ft thick coal bed x 1,770 tons/acre-ft for subbituminous coal = 17,700 tons of coal per acre)/ Keystone Manual, State and Federal publications, etc.
3. Minimum Coal Reserves Required	Generally, multiplied design capacity of mine (tons/year) times estimated life of mine/Keystone Manual, contractor's files, published literature, discussions with government and industry experts.
4. Mine Life	Often tied to expected life of steam-electric power plant (30 to 40 years) and to amortization of capital investment in mine/Sources as in (3) above.
5. Design Capacity	Analysis of mining plans, EIS's, trends in new mine developments, new legal requirements, trend toward mine-mouth power plants, etc./ Sources as in (3), plus unpublished government documents.
6. Mining Technology	Review of literature plus personal experience of contractor's staff and industry and government experts/Sources as in (3).

7. Coal Quality	Review of literature, compliation and manipulation of published data/Keystone Manual, State and Federal publications, etc.
8. Coal Thickness	Same as (7).
9. Markets	Analysis of published and unpublished data/Keystone Manual, State and Federal publications, discussions with industry and government experts, contractor's files, etc.
10. Coal Prices	Review of published and unpublished data/ Coal Outlook tables, U.S. DOE/EIA, etc.
11. Capital Requirements	Review and analysis of published and unpublished data/U.S. Geological Survey, Bureau of Mines, Bureau of Land Management, and Department of Energy; contractor's files.
12. Geology	Review of published and unpublished data/ Keystone Manual, State and Federal geological survey reports, contractor's files.
13. Transportation	Review and analysis of published and unpublished data/Colorado Energy Research Institute, various State and Federal publications, contractor's files, discussions with industry and government experts.
14. Mining Conditions	Review of published data/Keystone Manual, State and Federal publications, contractor's files and experience.

SUMMARY OF WESTERN U.S. COAL MINING TRENDS

During the past five years or so, most of the new mines that have opened in the Rocky Mountain region are large surface mines (±0.5-10+ million tons per year, mtpy) that mine subbituminous steam coal in single beds ranging from ±10 ft to more than 100 ft in thickness. Most of the very large new surface mines are located in the Northern Great Plains province (Wyoming and Montana); large surface mines that mine lignite are located in western North Dakota. In addition, medium to large surface mines (single-bed) have opened since 1970-1975 in the Rocky

Mountain coal province: subbituminous steam coal mines in the San Juan River region, New Mexico; and bituminous steam coal mines in the Green River region, Colorado. In 1977, a unique multi-bench surface mine opened in the Uinta region of Colorado. This mine, at peak capacity, is expected to surface-mine 8 to 10 bituminous coal beds, which aggregate approximately 60 ft in thickness, at rate of ±2 to 3 mtpy, for use in power plants in eastern Colorado and out-of-state. The long-term trend in states like Colorado, Utah, and Wyoming is toward an increase in underground-mined steam coal, in some areas mining deeper coal beds that underlie coals currently being surface-mined. The projection for metallurgical-grade (coking) coal, essentially all of which is underground-mined, is for little or no growth for the period 1980-1990. Projections for increases in production of western U.S. coal during the 1980's are hampered by present overcapacity in many of the existing mines (estimated at more than 100 mtpy in the West) and confusing signals from various Federal agencies (OSM, DOE, EPA, etc.) that appear to lack agreement on the role that coal is to assume in our Nation's serious energy dilemma.

COLORADO

Denver coal region: trend is toward medium-sized (0.5 to 0.9 mtpy) surface coal mines producing subbituminous steam coal.

Green River Coal region: Trend is toward a decrease in surface-mined coal and an increase in underground-mined bituminous steam coal, mostly from mines in the 0.5 to 1.9 mtpy range.

North Park coal region: trend is toward surface mines in the less than 1.0 mtpy range.

Raton Mesa coal region: trend is toward underground mines in the 0.5 to 0.9 mtpy range that will mine both steam and coking coal; and toward small surface steam coal mines (less than 0.5 mtpy).

San Juan River coal region: continuation of small (less than 0.1 mtpy) underground steam/domestic coal mines in the Durango area; trend toward larger mines may develop if and when a railroad is constructed into the Four Corners area.

Uinta coal region: trend is toward large surface steam coal mines in the 1.0 to 2.9 mtpy range; and large underground steam and coking coal mines in the 0.4 (or less) to 1.9 mtpy range.

MONTANA

Fort Union coal region, northern Powder River basin area: trend is toward large surface subbituminous coal mines in the ±5 to 20 mtpy range.

Fort Union coal region, Williston basin area: trend is toward large mines (1 mtpy or more) that will surface-mine lignite for use in steam-electric power plants and, possibly, for coal gasification.

NEW MEXICO

San Juan River coal region, San Juan basin fields: trend is mainly toward surface mining of subbituminous steam coal, primarily in the 2.0 to 3.9 mtpy range, with some smaller mines and some in the 3.0 to 5.9 mtpy range; a lesser trend is toward underground mines with design capacities of less than 2 mtpy.

Raton Mesa coal region, Raton field: little or no growth is anticipated during the next 5 to 10 years.

NORTH DAKOTA

Fort Union coal region, Williston basin area: trend is toward surface mines in the 1 to 6 mtpy range to provide lignite to power plants. Mines planned to provide lignite feedstock to proposed coal gasification plants are expected to be mostly in the 12 to 14 mtpy range.

OKLAHOMA

Interior coal province, Western region (southern part): trend is toward small surface mines with design capacities in the 0.2 to 0.4 mtpy range, to mine bituminous steam and coking coal.

UTAH

Uinta coal region, Book Cliffs field: trend is toward relatively large (0.2 to 1.0-plus mtpy) underground mines to produce bituminous steam coal.

Uinta coal region, Wasatch Plateau field: trend is essentially the same as for Book Cliffs field.

Uinta coal region, Emery field: trend is toward relatively large (0.5 to 1.0-plus mtpy) underground and surface mines to produce bituminous steam coal. Development may be hampered due to the lack of a rail line to the field.

Southwestern Utah coal region, Kaiparowits Plateau field: trend is toward relatively large (0.5 to 1.0-plus mtpy) underground mines to produce sub bituminous and bituminous steam coal. Development probably will be re tarded until a rail line is constructed into the region.

Southwestern Utah coal region, Alton field: trend is toward large (10-plus mtpy) surface mines to furnish subbituminous steam coal to planned new electric power plants in southwestern Utah and Nevada. Coal may be shipped via a slurry pipeline.

WYOMING

Green River coal region: trend is toward medium to large (0.5 to 6.8 mtpy) surface mines to produce both subbituminous and bituminous steam coal; and toward large underground mines to produce 1 to 2 mtpy of subbituminous and bituminous steam coal.

Ham's Fork coal region: trend is toward surface mines in the 1 to 5 mtpy category to produce subbituminous and bituminous steam coal.

Hanna coal field: trend is toward surface mines in the 1 to 5 mtpy range, and under ground mines in the 0.6 to 1.5 mtpy range, both categories to produce subbituminous steam coal.

Powder River coal region: trend in this, the most important coal-producing basin in Wyoming, is toward large surface mines, mostly in the 5 to 15 mtpy range, with some smaller and a few in the 15 to 20-plus mtpy range; all will produce subbituminous steam coal.

CRITERIA FOR CHARACTERIZING COAL MINES IN THE WESTERN UNITED STATES

CONVENTIONAL MINE DEVELOPMENT MODEL

COLORADO

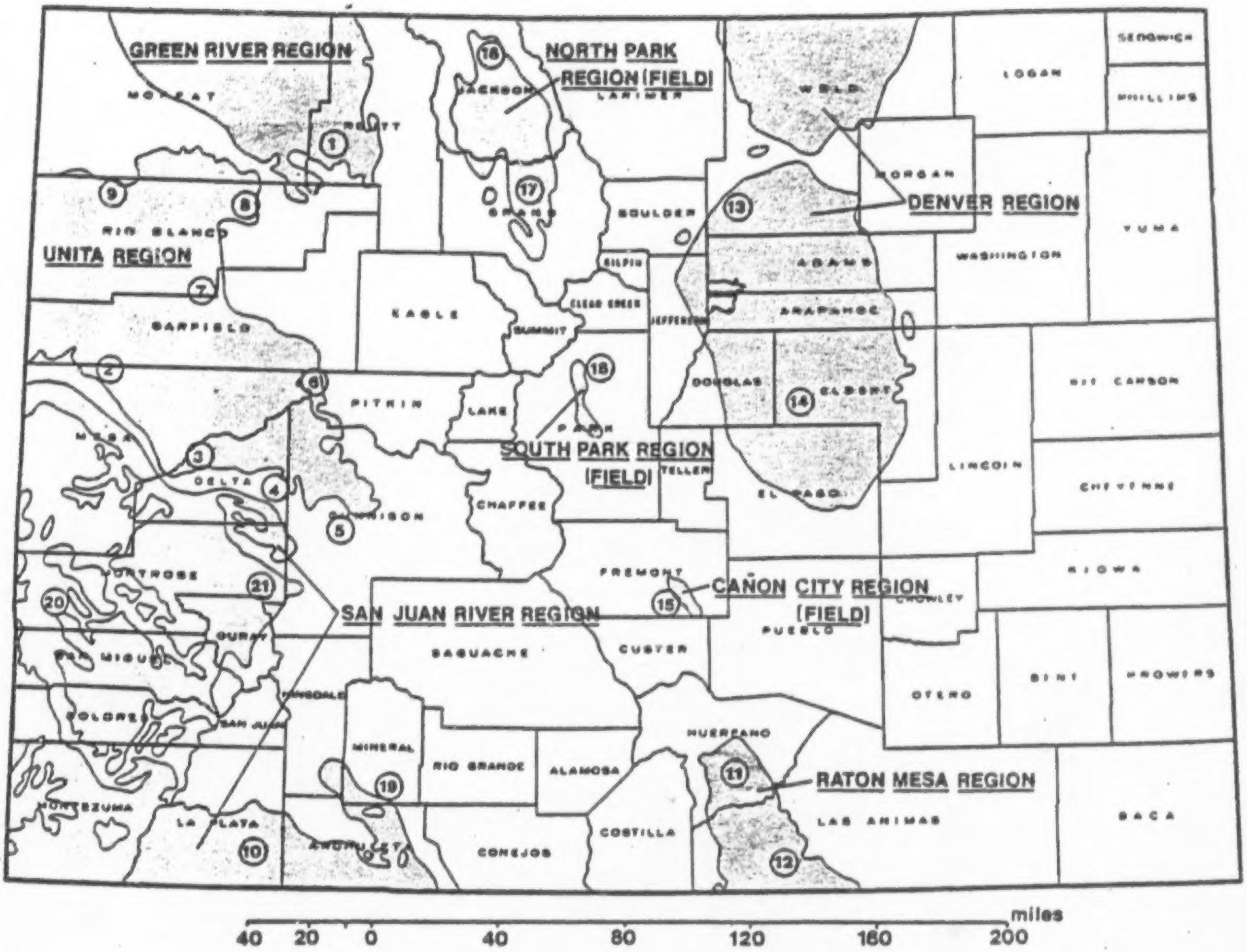
GENERAL STATEMENT

Coal is presently the largest available source of energy in Colorado. Coal deposits underlie almost 30,000 square miles of the State, or about 28% of its total area. Coal occurs in eight major regions which have been subdivided into 21 principal fields. These regions extend from the western Great Plains, through intermontane basins in the Rocky Mountains, into the Colorado Plateau (Fig. 1).

The State of Colorado ranks 7th in the total U.S. demonstrated reserve base of coal (16.3 billion short tons) and 4th in the reserve base of bituminous coal. Furthermore, Colorado ranks first in the reserve base of underground-minable, low-sulfur bituminous coal. A significant part of Colorado's bituminous coal reserve base is of coking or metallurgical grade.

Of the 434.21 billion short tons of identified and hypothetical coal resources estimated to be remaining in the ground in Colorado to a depth of 6,000 ft, only 128.95 billion short tons (29.7% of the total) are classed as remaining identified resources (to a depth of 3,000 ft) (Averitt, 1975, p. 14). However, these data are considered to be very preliminary, inasmuch as detailed or specific information on the occurrence and thickness of coal exists in only about 25% of the coal-bearing area of Colorado.

The estimated demonstrated reserve base of Colorado coals (as of January 1, 1976) is about 16.3 billion short tons, of which only 3.8 billion short tons (23% of the total) are surface-minable. The demonstrated reserve base includes all coals, except lignite, that occur at depths above 1,000 ft; only bituminous


GREEN RIVER REGION
NORTH PARK REGION (FIELD)
UNITA REGION
DENVER REGION
SOUTH PARK REGION (FIELD)
CAÑON CITY REGION (FIELD)
SAN JUAN RIVER REGION
RATON MESA REGION
MOFFAT
ROUTT
JACKSON
LARIMER
WELD
LOGAN
SEDGWICK
PHILLIPS
MORGAN
RIO BLANCO
GRAND
BOULDER
ADAMS
WASHINGTON
YUMA
GILPIN
CLEAR CREEK
JEFFERSON
ARAPAHOE
GARFIELD
EAGLE
SUMMIT
DOUGLAS
ELBERT
KIT CARSON
PITKIN
LAKE
PARK
MESA
DELTA
GUNNISON
CHAFFEE
TELLER
EL PASO
LINCOLN
CHEYENNE
MONTROSE
FREMONT
CROWLEY
KIOWA
OURAY
SAGUACHE
CUSTER
PUEBLO
SAN MIGUEL
HINSDALE
DOLORES
SAN JUAN
MINERAL
RIO GRANDE
ALAMOSA
HUERFANO
OTERO
BENT
PROWERS
MONTEZUMA
LA PLATA
ARCHULETA
CONEJOS
COSTILLA
LAS ANIMAS
BACA
1
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11
12
13
14
15
16
17
18
19
20
21
miles
40
20
0
40
80
120
160
200

Figure 1. Coal-bearing regions and fields in Colorado.

1. Yampa
2. Book Cliffs
3. Grand Mesa
4. Somerset
5. Crested Butte
6. Carbondale
7. Grand Hogback
8. Danforth Hills
9. Lower White River
10. Durango
11. Walsenburg
12. Trinidad
13. Boulder-Weld
14. Colorado Springs
15. Canon City
16. North Park
17. Middle Park
18. South Park
19. Pagosa Springs
20. Nucla-Naturita
21. Tongue Mesa

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coal and anthracite 28 in. or more in thickness, and subbituminous coal and lignite 60 in. or more in thickness, are included in the demonstrated reserve base. More than 80% of the total coal resources of the State (0-6,000 ft of overburden) probably will be minable only by underground methods. Overall recovery of the total resources of Colorado probably will be much less than 50% of the coal in-place, unless major breakthroughs in mining technology are achieved. Even then, the thick, multiple coal beds typical of many parts of Colorado may defy efficient overall recovery by even the most advanced mining methods now conceivable. In some instances, in-situ combustion of deeply buried or steeply dipping coal beds may be the only means by which to recover the energy contained in a large part of this State's coal resources.

Most of Colorado's potentially surface-minable coal is located in the Denver region (75% of the total -- mostly lignite), in the San Juan River region (Nucla-Durango-Cortez area, 16%), and in the Green River region (Oak Creek-Craig-Axial area, 5%).

Colorado coals range in age from early Late Cretaceous to Eocene. The higher rank bituminous coals, and the largest reserves, generally are found in the Upper Cretaceous Dakota and Mesaverde Groups/Formations in western Colorado, especially in the region from Garfield County south to the New Mexico State line. The oldest coals in Colorado occur in the Dakota Sandstone (or Group) in the southwestern part of the State (northern San Juan River region, Durango to Nucla-Naturita field areas). Successively younger coals were laid down as the Late Cretaceous Western Interior seaway retreated eastward and northeastward from the region.

The youngest coals, generally of lower rank (subbituminous A to lignite), are found in latest Cretaceous and early Tertiary rocks in the Green River, North and South Park, Raton Mesa, and Denver coal regions. Subbituminous coals occur in the Cretaceous Lance, Laramie, and Vermejo Formations; in the Paleocene Fort

Union and Raton Formations; and in the Paleocene-Eocene Wasatch and Coalmont Formations. Lignite is restricted to the Paleocene-age upper part of the Denver Formation in the central Denver coal region.

The San Juan River, Uinta, Green River, Raton Mesa, and Denver coal regions, for the most part, are located within Laramide-age structural basins. The interior areas of these basins appear to be relatively free from structural complications; the coal beds here probably are not highly folded, faulted, or otherwise disturbed. However, some of the margins of these structural basins are moderately to severely folded and faulted; in places, Tertiary igneous activity has metamorphosed the coal to anthracite and even to coke. The Uinta region, which is located partially within the Piceance Creek basin, and the Green River region, the Colorado portion of which includes the Sand Wash basin, each contain significant coal resources to depths exceeding 10,000 ft; these are the deepest structural basins in the State.

The Cañon City, North Park, and South Park coal regions occur in smaller, generally more structurally complex, Laramide-age basins.

Only a small part -- possibly 5% -- of the coal resources of Colorado today are considered to be surface-minable due to the limited areas within the coal-bearing regions in which the coal beds are both of gentle dip and under "shallow" cover.

Mining Method: During the 1980's, about 60% of the coal mines in Colorado will be underground mines, and about 40% will be surface mines, with one combined surface and underground mine. Colorado will be the only Western State, with the exception of Utah, to have more than a small number of underground mines, and it will be the only Western State where both surface and underground mining methods are widely used. By 1990, about 60% of the State's coal production will be from the 40% of the mines that are surface mines.

Mine Size: The current production capacity of major surface mines ranges from 0.1 to 4.0 million tons per year (tpy). In the future, the productive capacities of such mines will range up to 4.3 million tpy, although most mines will fall in the range of 1.0 to 2.9 million tpy, and a substantial portion will be even smaller (Tables 1 and 2).

The current production capacity of major underground mines ranges from 0.1 to 0.8 million tpy. In the future, the productive capacities of such mines will range up to 1.5 million tpy, although almost two-thirds of these mines will produce less than 1.0 million tpy (Tables 1 and 3).

Utilization: In 1976, about 39% of the coal produced in Colorado was shipped out of state to utilities and industries. Of the coal that was produced and used in Colorado, about 65% was for utilities for the generation of electricity, 28% was used for coke in steel mills, 6% was used by other industries, and 1% was used domestically. Overall, in recent years, about 20% of the State's production has been for coking and metallurgical purposes; and most of the balance of the coal has gone to utilities for the generation of electricity.

Future Potential: The potential for intensive development of Colorado's coal resources is good. Because Colorado possesses an abundance of coal that is low in sulfur, ash, and moisture and generally high in heating values, the State is in a position to meet at least some of the increasing demands for high quality steam and metallurgical-grade coal. Colorado has been a leading Western producer of coking coal for years, and contains two of the four major fields that account for most of the production of good quality coking coal in the West. The land ownership in Colorado is also favorable for development of coal resources, as about 75% of the coal resources occur on non-Federal land. One factor that may inhibit the development of coal resources is the lack of adequate railroad facilities in parts of Colorado so essential for the transporation of coal. This lack is particularly acute in the southwestern part of the State.

TABLE 1

Projected Design Capacities for Annual Production from Coal Mines in Colorado

(for mines producing at least 0.1 million tons per year by 1990)

Type of Mine	Number of Mines	Design Capacity (millions of tons per year) 0-0.4	0.5-0.9	1.0-1.9	2.0-2.9	3.0+
Surface[1]	15	2	3	4	5	1
Underground[2]	22	7	7	8	0	0
Total	37	9	10	11	5	1

[1] This does not include three surface mines, with design capacities of 4.0, 0.4, and 0.2 million tons per year, that are active now but that will cease production by 1990.

[2] This does not include one underground mine, with a design capacity of 0.3 million tons per year, that is active now but that will cease production by 1990. This does include one combined surface and underground mine with a design capacity of 0.6 million tons per year.

TABLE 2

Projected Design Capacities for Annual Production from Surface Coal Mines in Colorado

(for mines producing at least 0.1 million tons per by 1990)

Region	Number of Mines	Design Capacity (millions of tons per year)				
		0-0.4	0.5-0.9	1.0-1.9	2.0-2.9	3.0+
Uinta	8[1]	1	1	2	3	1
Green River	3[2]	0	0	2	1	0
North Park	3	1	1	0	1	0
Denver	1	0	1	0	0	0
Total	15	2	3	4	5	1

[1] This does not include one mine, with a design capacity of 0.2 million tons per year, that is active now but that will cease production by 1990.

[2] This does not include two mines, with design capacities of 4.0 and 0.4 million tons per year, that are active now but that will cease production by 1990.

TABLE 3

Projected Design Capacities for Annual Production from Underground Coal Mines in Colorado

(for mines producing at least 0.1 million tons per year by 1990)

Region	Number of Mines	Design Capacity (millions of tons per year) 0-0.4	0.5-0.9	1.0-1.9	2.0-2.9	3.0+
Uinta	9	4	1	4	0	0
Green River	8	3	2	3	0	0
San Juan River	1	0	0	1	0	0
Raton	3[1]	0	3	0	0	0
Cañon City	1	0	1	0	0	0
Total	22[2]	7	7	8	0	0

[1] This includes one combined surface and underground mine that will have a design capacity of 0.6 million tons per year.

[2] This does not include one mine, in the Denver basin, with a design capacity of 0.3 million tons per year, that is active now but that will cease production by 1990.

Colorado coal production for 1979 is projected to be more than 18.3 million short tons, an increase of some 28% over 1978. Production for 1980 may total nearly 23 million tons; for 1985, nearly 30 million; and for 1990, approximately 32 million short tons, according to recent estimates made by the Colorado Energy Research Institute. Recent estimates by the Department of Energy place productive capacity at even higher levels over the next decade: 38.0 million tons for 1985, and peak of 41.8 million tons for 1987, and 39.8 million tons for 1990.

COAL CHARACTERISTICS

Rank: Colorado coals range in rank from lignite to anthracite; over 70% of the State's coal resources are bituminous, approximately 23% subbituminous, 5% lignite, and less than 1% anthracite.

In a general sense, the older the coal, the higher the rank; however, geologic factors such as higher geothermal gradient and deeper burial can significantly increase the rank of even the youngest coals.

For the most part, coals in Colorado are low-slacking. Many also are nonagglomerating, although significant resources of coking coal are found in parts of the Uinta, San Juan River, and Raton Mesa regions (see discussion below).

The coal-bearing sequences and coal ranks, by region, can be generalized as follows (units currently being mined are underscored):

CAÑON CITY REGION (OR FIELD):

Vermejo Formation (Upper Cretaceous) --

high-volatile C bituminous

DENVER REGION:

Denver-Dawson Formations (Paleocene part) --

lignite A to subbituminous C

Laramie Formation (Upper Cretaceous) --

subbituminous B and C

GREEN RIVER REGION:

Wasatch (Eocene), Fort Union (Paleocene), and Lance (Upper Cretaceous) Formations -- probably mostly subbituminous B and C.

Mesaverde Group (Upper Cretaceous) -- mostly high-volatile C bituminous some high-volatile B bituminous and subbituminous A.

NORTH PARK REGION (OR FIELD):

Coalmont Formation (Paleocene-Eocene) -- subbituminous A and B.

RATON MESA REGION:

Northern part of region (Walsenburg coal field):

Raton Formation (Paleocene-Upper Cretaceous) -- high-volatile B and C bituminous (non-coking)

Vermejo Formation (Upper Cretaceous) -- high-volatile B and C bituminous (non-coking)

Southern part of region (Trinidad coal field):

Raton Formation (Paleocene-Upper Cretaceous) -- high-volatile A and B bituminous (generally of coking quality).

Vermejo Formation (Upper Cretaceous) -- high-volatile A and B bituminous (generally of coking quality).

SAN JUAN RIVER REGION:

Fruitland Formation (Upper Cretaceous) -- high-volatile B and C bituminous

Menefee Formation of Mesaverde Group (Upper Cretaceous) -- high-volatile A and B bituminous (locally of coking quality)

Dakota Formation or Group (Upper Cretaceous) -- high-volatile B and C bituminous (currently mined only in Nucla-Naturita field; may locally be of coking quality).

SOUTH PARK REGION (OR FIELD):

Laramie Formation (Upper Cretaceous) --

subbituminous A and B (not produced since 1932).

UINTA REGION:

Mesaverde Group (Upper Cretaceous) --

anthracite and semianthracite (restricted to areas of igneous activity in southeastern part of area, especially in Crested Butte field); medium-volatile bituminous (high-grade coking coal, chiefly in Coal Basin area of Carbondale field); high-volatile A, B, and C bituminous (of coking quality in parts of Carbondale and Somerset fields); subbituminous A and B (?) (only in local areas near outcrops).

Sulfur Content: Sulfur contents of most Colorado coal beds vary from 0.2-1.2%, as-received. More than 99% of the coals analyzed contain less than 1.0%; and more than 50%, less than 0.7% sulfur. The bulk of the coal being surface-mined in Colorado at present (over two-thirds of the State's production in 1978 was from surface mines) contains between 0.2 and 0.5% sulfur; on the other hand, much of the underground-mined metallurgical-grade coal in Colorado contains 0.5-1.0% sulfur, still low in comparison with many Eastern coals. Recent work by the U.S. Geological Survey and the Colorado Geological Survey indicates that organic sulfur usually predominates, followed by pyritic sulfur and sulfate. A typical coal in the Yampa field, Green River region, shows the following forms-of-sulfur analysis: organic, 0.49%; pyritic, 0.03%; and sulfate, 0.03%; total sulfur, 0.55%. Abnormally high pyrite content can be reduced by conventional coal preparation techniques to 0.5% sulfur or less. In terms of pounds of sulfur per million Btu, most of the coal being surface-mined in Colorado today for use in steam-electric power plants contains between approximately 0.2 and 0.5 lb/million Btu, well within the definition of low-sulfur coal: namely, one which contains 0.6 lb or less sulfur per million Btu.

Heating Values: Most of the subbituminous and bituminous steam coal being produced today in Colorado ranges from about 10,000-13,600 Btu/lb; and coking coal, from 12,070 to over 14,000 Btu/lb, as-received. On a dry, ash-free basis, an average of approximately 14,000 Btu/lb is reasonable for most Colorado coals; and on an as-received basis, about 11,370 Btu/lb.

Moisture Content: As-received moisture contents generally range from 1% to 20%, but some of the subbituminous coals and lignites in the Denver region have moisture contents as high as 38%. Statewide, coal in Colorado averages about 12% moisture.

Volatile Matter: Volatile matter contents range across the State from 6.9%, for anthracite in the Crested Butte Field in the Uinta region, to about 45%. Most coals have volatile matter contents of 31% to 40%.

Ash Content: The ash contents of coal beds in Colorado vary considerably as a result of different environments of depositon, even within the same coal "zone." The range typcially is from approximately 2% to 20%, averaging about 6%. Locally, however, ash contents may reach 25% to 30%, as-received.

COAL CONVERSION

The varied coal resource of Colorado contain reserves of different types suitable for conversion, including lignites and subbituminous coals suitable for gasification, and high-volatile bituminous coals suitable for liquefaction. There are reports of a proposed high-Btu coal gasification plant to be located east of the City of Denver, which would utilize nearby lignite reserves as feedstock. However, no future coal production is reported to have been committed to conversion plants that may some day be constructed in Colorado.

DENVER REGION

The Denver coal region includes an area of about 7,500 square miles east of the Front Range of the Rocky Mountains on the western Great Plains. The Denver region extends northward from near Colorado Springs to the Wyoming border. The region consists of two separate sub-basins, the Denver sub-basin to the south and the Cheyenne sub-basin to the north. These basins are separated by the Greeley arch, from which the coal-bearing formations have been eroded.

The remaining in-place resources to depths of 3,000 ft in the Denver region have recently been estimated at 30 to 40 billion tons. This includes about 20 to 25 billion tons of subbituminous coal in the Cretaceous Laramie Formation, which occurs in both basins, and about 10 to 15 billion tons of lignite, in the Upper Cretaceous to Paleocene Denver Formation, which is found only in the Denver sub-basin.

Since the late 1800's, the Denver coal region has produced more than 130 million tons of coal, some 20% of the Statewide total, from approximately 385 mines, virtually all of them underground. Approximately 15 million tons of all the production in the region (or 12%) came from the Colorado Springs field (in Douglas, El Paso, and Elbert Counties). The balance was mined in the Boulder-Weld field, most of the coal being produced in Boulder and Weld Counties. The Colorado Springs field has produced no coal since 1957. This is the only coal region in Colorado in which shaft mining has predominated over drift or slope mining. Shaft depths here have ranged from about 250-500 ft.

During 1978, the lone mine operating in the entire region (the Lincoln, in Weld County) produced 72,909 tons of subbituminoius steam coal; overburden thickness in this mine is approximately 425 ft. This mine now is closed. Although underground mining in the past has predominated in the Denver region, the only mine planned to produce throughout the next decade is a new surface mine.

I. REPRESENTATIVE MINING OPERATIONS

A. Coal Rank: Coals in the Laramie Formation range in rank from subbituminous B to lignite A. The higher ranks occur in the western part of the Denver basin and in the Boulder-Weld field. In the Denver Formation all of the known resources are lignite.

B. Minimum Leasehold Requirement: The minimum leasehold requirements will vary widely depending on the thickness of the bed mined. Typical subbituminous coal or lignite beds in the Denver region range in thickness from 3 ft to 30 ft (a few beds are thicker), so that there may be at least a 10-fold variation in leasehold requirements. For mines with a recoverable reserve base of 2 million tons, which would support a mine producing 0.1 million tons per year (tpy) for 20 years, a recovery rate of 50% for underground mines, and a bed thickness of 30 ft, the leasehold required would be about 75 to 100 acres. For thinner beds or larger mines, the leasehold required would increase proportionately, up to as much as several hundred acres or more.

C. Minimum Recoverable Reserves Requirement: The current level of mining in this area is too low to be used as a basis for estimating minimum recoverable reserves. Over the course of the history of this region, its mines each have produced an average of about 0.33 million tons of coal. The statewide trend in mining, including mines in this region, is for mines that will produce at least 0.1 million tpy. For mine lives of 20 years, this amounts to recoverable reserves of 2 million tons.

D. Mine Life: 20 to 30 years.

E. Coal Price, FOB Mine: Recent spot market prices for coal from Colorado with less than 0.75% sulfur range from $17 per ton for coal of 10,500 Btu/lb to $20 per ton for coal of 11,500 Btu/lb.

F. Design Capacity: There are few specific data on the trend of mine sizes in this area. For the State as a whole, most underground mines will have annual productive capacities of less than 1 million tons. However, a relatively large number will have capacities that range between 1 and 2 million tpy (Tables 1 and 3).

G. Mining Technology: Historically, this is the only area of Colorado in which shaft mines have predominated over drift or slope mines. There is the potential for underground mines that would be large enough (larger than about 0.7 million tpy) to use longwall mining techniques, although the relatively low rank of Denver basin coals may preclude its use.

H. Capital Requirements: \$35 to \$40 million (±20%) are required for an underground mine producing 1 million tpy; \$15 to \$20 million (±20%) are required for a surface mine of the same capacity.

I. Labor Requirements: Detailed data are not available for the Denver region. In Colorado as a whole, in 1978, there were 41 underground mines that employed 1,856 people and produced 4,452,864 tons of coal. This results in averages of 0.11 million tons per mine, produced by about 45 people per mine, at an annual rate of about 2,450 tons per employee. Employee productivity in Colorado appears to be somewhat lower than at the larger underground coal mines in Wyoming and Montana.

J. Surface Equipment: Surface mines in this area would require surface-mining equipment, including shovels, trucks, bulldozers, scrapers, loaders, graders, and draglines. Both surface and underground mines might require such equipment as railroad spurs, haul roads, coal handling, loading, and storage equipment, conveyors, and offices.

K. Proximity to Transportation: This area is well served by main and branch lines of the Burlington Northern Railroad; its subsidiary, the Colorado and Southern Railroad; the Union Pacific Railroad; and the Chicago, Rock Island, and Pacific Railroad. Additionally, this area is served by a well-developed network of State and Federal highways.

L. Common Transportation Mode: Most mines would probably transport their coal short distances by truck or conveyor to railroad loading facilities.

M. Community Infrastructure Requirements: There are many small cities and towns in this region that could probably support substantial development of coal resources. Whether or not a reservoir of trained manpower exists in these areas as a result of their history of mining is unknown.

II. GENERAL MINING CONDITIONS

A. Structural Attitudes: The Denver coal region lies within the larger Denver structural basin. This basin is asymmetric, with its axis toward the western edge. The Denver structural basin includes two sub-basins, the Cheyenne sub-basin to the north and the Denver sub-basin to the south, which are divided by the roughly east-west trending Greeley Arch. Beds of the Upper Cretaceous Laramie Formation are exposed in the foothills of the Front Range from near Colorado Springs to Boulder. In the Foothills District, the beds are steeply dipping to near-vertical, but their dips decrease rapidly eastward to 5° or less. The structure of the margins of the sub-basins is typically complicated by faulting and folding, but the centers of the sub-basins are relatively free of structural complexities.

B. Topographic Relief: The physiography of the Denver region is typical of the western Great Plains. Relief is low, upland areas and valley bottoms are typically broad and flat, and streams are locally slightly entrenched. Slopes are generally gradual except where stream erosion has created short scarps.

C. Maximum Overburden: Beds beneath less than 200 ft of overburden are considered potentially surface minable in the Denver region. Surface-minable subbituminous coal beds in the Laramie Formation occur beneath about 1,850 square miles of the Denver region. An additional 2,000-plus square miles contain

Laramie coals at depths of 500 ft to 1,500 ft. Most of the lignite in the Denver Formation is also considered surface minable.

Typical shaft depths for underground mines in the Denver region have ranged from about 250 ft to 500 ft, and the single underground mine operating in 1978 had overburden of about 425 ft.

D. Market: The single mine operating in the Denver region in 1978 was under contract to supply coal to the Adolph Coors Company plant in Golden. The initial markets for the coal from this area may be local, including existing municipal power plants that must convert to burning coal. In the future, additional markets for steam coal or coal for conversion may develop in this area or in adjacent areas in the Midwest and Texas. Markets for coal from the Denver region are probably limited to north, northeast, and west because in those areas there are abundant resources that are already under active devlopment.

III. TYPICAL COAL BED CHARACTERISTICS

A. Analyses, As-Received: Analyses of coal, as-received, from the Denver region, are summarized in Table 4.

B. Thickness of Coal: The thickness of coal beds in the Laramie Formation typically ranges from 5 ft to 10 ft, with a maximum of about 20 ft, in the Denver sub-basin, and from 3 ft to 7 ft in the Cheyenne sub-basin. The thickness of lignite beds in the Denver sub-basin typically ranges from 10 ft to 30 ft, with a maximum of 55 ft, in the north, and from 5 ft to 10 ft, with a maximum of about 30 ft, in the south.

C. Mining Problems: The major mining problems in this region in the past involved subsidence resulting from relatively shallow (less than 300 ft of overburden) underground mining. Some problems due to faulting and burning coal exist, particularly in the Boulder-Weld coal field.

TABLE 4

Range of Analyses of Coals from the Denver Region (As-Received)

Area or Field and Coal Beds	Moisture %	Volatile Matter %	Ash %	Sulfur %	Heating Value Btu/lb
Boulder-Weld, Laramie Fm. (Beds 1-7)	13.7-29.1	27.3-43.6	3.5-12.7	0.2-0.9	8,250-10,810
Colorado Springs, Laramie Fm. (Beds A, B, C)	19.0-26.2	31.4-45.1	5.6-20.8	0.3-0.7	8,400-9,20
S.E. & So.-Central, Denver Fm. (Bijou, Kiowa, Comanche)	26.4-39.6	19.3-42.7	9.8-44.6	0.2-0.6	3,636-6,803
Laramie Fm.	33.1-35.0	30.8-44.2	7.8-15.7	0.4-1.1	6,150-7,340

GREEN RIVER REGION

The southeast arm of the large Green River coal region is located in Moffat and Routt Counties of northwest Colorado. The larger part of this important coal region covers most of southwest Wyoming. The Colorado part of this region is comprised of the Sand Wash structural basin of Laramide age, together with the north flank of the Axial Basin uplift, which includes the Williams Fork Mountains and forms the south edge of the basin. The perimeter of the Green River coal region is defined, except where faulted, by the base of the Upper Cretaceous Mesaverde Group. The oldest coals in the region are found in the Iles Formation, lower Mesaverde Group.

Coal-bearing Upper Cretaceous, Paleocene, and Eocene rocks crop out along the Yampa River-Williams Fork Mountains area, in the southeastern part of the region. This area constitutes the Yampa Coal field, the only named field in the region. The south flank of the Sand Wash basin consists of gently northward-dipping sediments that are locally folded, especially in the southeast part of the basin, and complicated by faulting and igneous intrusives of late Tertiary age, which, in places, have upgraded some of the coals to anthracite.

Virtually all of the coals mined to date in the Green River region have come from the Iles and Williams Fork Formations of the Mesaverde Group. Younger coal-bearing rocks (Lance, Fort Union, and Wasatch Formations) are preserved toward the interior of the basin, away from outcrops of the Mesaverde, on or near which most of the coal mining to date has taken place. A major part of the region contains multiple coal beds in several formations below a depth of 3,000 ft (in the central part of the Sand Wash basin, coals are present to depths in excess of 10,000 ft).

This region to date has produced more than 95 million short tons of coal (or approximately 15% of the State's coal) from nearly 200 mines. During 1978, more than 9.38 million tons of coal were produced in the Green River region, Colorado, which is about two-thirds of all of the coal produced in the State. Production at that time was from 12 surface and 2 underground mines; surface mining also predominated in actual volume. During the coming decade, underground mining will become predominant, at least for mines producing more than 0.1 million tons per year (tpy) (Tables 2 and 3).

Total in-place coal resources of the Colorado part of the Green River region probably far exceed 60 billion tons above a depth of 6,000 ft, although very little work has been done so far in evaluating the coals below "minable" depths. Nearly 1 billion tons of potentially surface-minable coal may exist in this part of the region.

I. REPRESENTATIVE MINING OPERATIONS

A. Coal Rank: The Mesaverde coals in the Green River region, for the most part, are high-volatile C bituminous in rank. The younger Lance Formation coals, which have been mined only locally in the past (but are not mined at present), appear to be subbituminous B or C. The overlying Fort Union coals, where sampled near the surface, appear to be subbituminous B or C in rank. Very little is known about the Wasatch Formation coals in the Colorado part of the region, although they have been mined in limited quantities at several ranches on both sides of the Colorado-Wyoming State line. Like the older Fort Union and Lance coals, those in the Wasatch Formation probably are subbituminous B or C in rank.

B. Minimum Leasehold Requirement: The smallest surface mine currently anticipated to operate in the Green River region throughout the next decade will have an annual productive capacity of 1 million tpy. Assuming a minimum mine life of 20 years and a recovery factor of 85%, a mine such as this would require reserves of at least 23.5 million tons. For bituminous coal 10 ft thick, which is typical of the beds now mined, the leasehold required would be about 1,300 acres. Some beds range up to 20 ft in thickness, and a few may be as thick as

40 ft. For such beds the leaseholds required would be proportionally less for mines of a given capacity.

The smallest underground mine currently anticipated to operate through the next decade in the Green River region would have an annual production capacity of 0.3 million tpy. Underground mines can generally be expected to have lives comparable to surface mines, but the underground recovery factor is 50% or less. Thus, for a given bed thickness, the minimum leasehold required for an underground mine amounts to about double of that for a surface mine, or 120 to 140 acres for a mine in a coal bed about 10 ft thick per million tons produced.

C. Minimum Recoverable Reserves Requirement: For a surface mine producing 1 million tpy for 20 years, the required recoverable reserves would be 20 million tons. For an underground mine producing 0.3 million tpy for 20 years, the required recoverable reserves would be 6 million tons.

D. Mine Life: 20 to 30 years.

E. Coal Price, FOB Mine: Recent spot market prices for coal from Colorado with less than 0.75% sulfur range from $16 per ton for coal of 10,500 Btu/lb, to $20 per ton for coal of 11,500 Btu/lb.

F. Design Capacity: The design capacity of surface mines that plan to operate over the coming decade in the Green River region ranges from 1.0 to 2.5 million tpy (Table 2). The design capacity of underground mines in the coming decade ranges from 0.3 to 1.5 million tpy, but most underground mines should produce less than 1 million tpy (Table 3).

G. Mining Technology: Standard technologies should be employed for both surface and underground mines in the Green River region. If historic precedent is followed, most of the underground mines in the region will be drift or slope mines, although shaft mines eventually will operate in the deeper parts of the basin.

H. Capital Requirements: For a surface mine of 1 million tpy capacity, $15 to $20 million (±20%) is required. For an underground mine of similar capacity, $35 to $40 million (±20%) is required.

I. Labor Requirements: In recent years in the Green River region, the productivity of employees in underground mines has ranged from 455 to 5,000 tons per employee per year, with an average of 2,815 tons per employee per year. The productivity of employees in surface mines has ranged from 1,747 to 101,000 tons per employee per year, with an average of 20,992 tons per employee per year.

J. Surface Equipment: Surface mines would have standard surface mining equipment, such as draglines, scrapers, front-end loaders, bulldozers, graders, shovels, and trucks. Both surface and underground mines would have such support facilities as railroad spurs and haul roads, coal handling, loading, and storage facilities, conveyors, and offices.

K. Proximity to Transporation: Central Routt County and a small area of eastern Moffat County are served by branches of the Denver and Rio Grande Western Railroad. Additionally, there are several State highways in the region.

L. Common Transportation Mode: Trucks are used to ship coal to nearby consumers or to railroad facilities from which the coal is shipped on unit trains.

M. Community Infrastructure Requirements: There are a few small towns in the area that may be able to supply some trained manpower above present needs. Two large coal-fired electric generating plants exist in the region.

II. GENERAL MINING CONDITIONS

A. Structural Attitudes: Detailed structural data for the entire Green River region are not readily unavailable. In the Sand Wash structural basin, the beds dip northward at low to moderate angles. The structure is complicated by faulting and igneous instrusions and, especially in the southeastern part of the basin, by folding. The beds that have been mined in recent years dip generally northward at angles of from 1° to 15°.

B. Topographic Relief: Except for the Williams Fork Mountains and Elkhead Mountains part of the coal region, the topography is generally rolling and of moderate relief, with some dissection by streams and rivers.

C. Maximum Overburden: A large part of the region contains several coal beds at depths below 3,000 ft; and in the center of the Sand Wash basin, the coals are buried to depths of more than 10,000 ft. Overburden thicknesses at the recently active underground mines range up to about 1,000 ft. Overburden thicknesses for active and proposed surface mines typically range from 30 ft to 300 ft.

D. Market: Most of the coal (all of it low sulfur) being mined in the Green River region is or will be burned in steam-electric generating plants located within the region, at Craig and Hayden; elsewhere in Colorado, mostly in the Denver area; or exported to States such as Illinois, Iowa, Nebraska, and Texas.

III. TYPICAL COAL BED CHARACTERISTICS

A. Analyses, As-Received: Typical analyses of coal from the Green River region are shown in Table 5.

B. Thickness of Coal: The Mesaverde coals are about 3 ft to 20 ft thick, the Lance coals are up to 10 ft thick, the Fort Union coals are up to 40 ft thick, and the Wasatch coals are from a few feet to 20 ft or more in thickness.

C. Mining Problems: No severe mining problems are known to exist in the region. Some water flows can be expected from artesian aquifers above or below the coal beds in some of the synclinal parts of the region, where deep underground mines have been proposed.

TABLE 5

Range of Analyses of Coals from the Green River Region (As-Received)

Area or Field and Beds	Moisture %	Volatile Matter %	Ash %	Sulfur %	Heating Value Btu/lb)
Yampa					
Fort Union Fm. (Seymour)	20.7-23.0	--	3.9-7.8	0.2-0.4	8,250-8,710
Lance Fm. (Lorella, Kimberly)	19.6-21.8	--	4.1-6.5	0.5-0.7	9,660-9,720
Williams Fork Fm., "Upper Coal Gp." (Dry Creek, Crawford, Fish Creek)	9.8-16.9	34.9-39.2	4.1-17.2	0.4-1.8	9,800-11,680
Williams Fork Fm., "Middle Coal Gp." (Lennox, Wadge)	6.4-11.8	33.8-39.0	3.0-20.2	0.3-0.9	9,871-12,440
Iles Fm., "Lower Coal Gp." (E,D,C,B,A or Pinnacle)	6.3-12.2	--	4.3-11.3	0.3-0.9	11,090-12,500

NORTH PARK REGION (OR FIELD)

The North Park coal region, located in Grand and Jackson Counties, lies in a high (8,000-9,000 ft) intermontane structural basin in north-central Colorado. The North Park basin, or syncline, of Laramide age, is bounded by the Medicine Bow-Front Range uplift on the east, the Park Range uplift on the west, the Independence Mountain thrust fault on the north (near the Wyoming State line), and the Williams River-Vasquez Mountains on the south. The North Park region is comprised of two topographic basins, North Park and Middle Park, separated by the east-west trending Rabbit Ears Range, a middle to late Tertiary volcanic field composed of both flows and intrusive bodies. North Park coal field lies in North Park, Jackson County; and Middle Park coal field, in Middle Park, Grand County.

All of the coals found in North Park basin occur in the Coalmont (Middle Park) Formation of late Paleocene and early Eocene ages, which may aggregate as much as 12,000 ft in thickness. The Coalmont consists of terrigenous clastics, carbonaceous shales, and coals, laid down in an alluvial basin that rapidly subsided as the Rocky Mountains were uplifted in early Tertiary time. Coals were formed in flood basins and swamps between meandering streams. The Coalmont Formation unconformably overlies the marine Pierre Shale (Upper Cretaceous).

North Park Coal field is the only part of the region in which coal has been mined, from the Coalmont district and the McCallum anticline district. The North Park region has produced nearly 3.7 million tons of coal from 35 mines since the early 1900's. During 1978, the region produced 642,066 short tons of steam coal from two surface, or open-pit mines, the Canadian and the Kerr, located on the east flank of McCallum anticline (which produces oil and gas from Lower Cretaceous sandstones). This production represents a 29% increase over 1977 and was about 4.5% of the total output for the State.

Middle Park Field never has produced coal, although some coal beds have been reported in lower Tertiary sediments that probably are correlative with the Coalmont Formation in North Park, a few miles to the north. An unknown amount of coal resources probably exists within this 250-300-square-mile southern extension of North Park basin.

I. REPRESENTATIVE MINING OPERATIONS

A. Coal Rank: Most coals in the North Park region are subbituminous A to B in rank. Most of the coals mined recently in this area have been subbituminous A. The rank of these coals has probably been upgraded somewhat because of the abnormally high heat flow in parts of the area.

B. Minimum Leasehold Requirement: The smallest mine that is currently planned to produce through the next decade in this area is a surface mine with an annual capacity of 0.2 million tons per year (tpy). Assuming that this mine will produce for 20 years, it will require a total of 4 million tons of recoverable coal. If a 50-ft-thick bed is mined, which is typical of the bed currently being mined, and the recovery factor is 85%, then the leasehold required for the reserves described above will be about 50 acres.

C. Minimum Recoverable Reserves Requirement: About 4 million tons will be required by a mine of the smallest currently planned capacity.

D. Mine Life: Some of the current mines in the region have projected lives of only several years. The larger planned mines should produce for longer periods, however.

E. Coal Price, FOB Mine: Recent spot market prices for coal from Colorado with less than 0.75% sulfur range from \$17/ton for coal of 10,500 Btu/lb to \$20/ton for coal of 11,500 Btu/lb.

F. Design Capacity: The three mines projected to operate over the next decade in the North Park field, all of which are surface mines, have proposed design capacities of 0.2, 0.7, and 2.0 million tpy (Table 2). However, smaller mines have operated there in the recent past.

G. Mining Technology: Recent mines have used standard surface-mining techniques centered around bulldozers and scrapers.

H. Capital Requirements: $15 to $20 million (±20%) of capital are required for a surface mine of 1 million tpy capacity.

I. Labor Requirements: Employee productivity in recent years from the two operating mines in North Park field has ranged from 1,692 tons per employee per year to 8,908 tons per employee per year, with an average of 5,544 tons.

J. Surface Equipment: Surface mines in this region utilize such mining equipment as trucks, bulldozers, scrapers, and loaders, as well as support facilities such as haul roads and railroad spurs, coal loading and storage facilities, and offices.

K. Proximity to Transportation: This region is served by a light-duty branch line of the Union Pacific Railroad and by several State and County roads.

L. Common Transportation Mode: Coal that is consumed locally is transported by truck; coal that is shipped out of the region is transported by rail.

M. Community Infrastructure Requirements: The small community of Walden is the only one in the basin that is able to support the present mining activity and that may be adequate to support the planned moderate expansion of mining.

II. GENERAL MINING CONDITIONS

A. Structural Attitudes: The North Park region is somewhat more structurally complex than are most of the larger coal-bearing basins in Colorado. In the North Park coal field, the beds are commonly highly folded, with dips in excess of 45° in areas such as McCallum anticline. In the two active mines, the beds dip from 45° to 60°. The coal beds also are typically faulted.

B. Topographic Relief: Most of North Park basin is flat-lying to gently rolling and presents few, if any, mining problems. Meandering streams course through most of the coal-bearing areas.

C. Maximum Overburden: There are few data on overburden in the region. However, for the two active surface mines, the overburden is 20 ft to 25 ft in one case and 230 ft in the other. The individual coal beds range in thickness up to 60 ft, and favorable stripping ratios can be found even in areas of thick overburden.

D. Market: This region produces steam coal for local use and for industries and electric utilities elsewhere in Colorado and in Illinois.

III. TYPICAL COAL BED CHARACTERISTICS

A. Analyses, As-Received: Representative analyses are summarized in Table 6.

B. Thickness of Coal: Coal beds in the region generally range from about 8 ft to 60-plus ft in thickness.

C. Mining Problems: The steeply dipping beds in parts of this region present some difficulties for mining. Faulting can result in severe discontinuities in coal-bed distribution and can make it difficult to accurately estimate coal resources and reserves.

TABLE 6

Range of Analyses of Coal from the North Park Region (As-Received)

Field, District, and Beds	Moisture %	Volatile Matter %	Ash %	Sulfur %	Heating Values Btu/lb
North Park Field					
Coalmont District					
Coalmont Fm., (Riach; Beds 4, 3, 2, 1; Monahan)	14.5-20.2	29.3-37.3	5.5-13.1	0.6-1.0	6,520-9,570
McCallum Anticline District					
Coalmont Fm. (Hill, Winscom, Sudduth)	12.0-16.1	27.4-37.3	2.1-19.2	0.2-0.3	8,580-11,280

RATON MESA REGION

The Colorado part of the Raton Mesa coal region extends northward from the Colorado-New Mexico State line to just north of the town of Walsenburg, and from the prominent Sangre de Cristo and Culebra Ranges eastward to Interstate Highway 25 and the town of Trinidad. This region lies within the Laramide-age Raton structural basin.

The perimeter of the Raton Mesa coal region is defined by the base of the Vermejo Formation (Upper Cretaceous), which is the oldest coal-bearing sequence in the basin. Immediately above the Vermejo is the coal-bearing Raton Formation, of Upper Cretaceous-Paleocene ages. The multiple, lenticular coal beds in both of these sequences generally are less than 10 ft in thickness.

The coals of both formations in the southern part of the Colorado portion of the region -- essentially, Las Animas County -- generally are of coking quality, whereas those in the northern part -- primarily in Huerfano County -- typically are non-coking.

The Raton Mesa region (Colorado portion) has produced more than 247 million tons of coal to date from approximately 370 mines; this represents nearly 40% of all of the coal produced in Colorado. This region has produced more coal, by far, than any other region in the State -- at least 115 million tons more than the second place Denver region. Despite the large volume of coal that has been removed from the Raton Mesa region, more than 94% of the estimated in-place resource of 13.2 billion tons still remains in the ground.

Essentially all of the mining to date in the region has been in the thicker, higher quality Vermejo coals. The mines have been located along the escarpment at the eastern edge of the basin and along the drainage of the eastward-flowing Purgatoire River, which dissects the area west of Trinidad.

The Raton Mesa region consists of two major coal fields, the Trinidad and the Walsenburg.

The Trinidad coal field has produced considerable coal since the late 1800's, much of it of coking quality -- approximately 174 million tons through 1978, or more than 27% of the total for the entire State, from more than 150 mines, most of them underground.

Most of the 1978 production from the Trinidad field came from CF&I Steel's two captive coking coal mines, the Allen and the new Maxwell, which together accounted for approximately 582,000 tons of coal, or some 87% of the field's total production for the year. Six small surface mines produced the balance. Coal from the CF&I mines is shipped by rail to the company's steel mill in Pueblo, approximately 150 miles to the north, where it is coked.

The Walsenburg coal field, in Huerfano County, so far has produced more than 75.5 million tons of coal, mostly non-coking, which is about 12% of the cumulative production to date in Colorado. Most of this coal has been mined from the lower part of the Vermejo Formation. No coal was mined in this field for a number of years until October 1978, when a small surface mine was opened; this mine has produced more than 61,000 tons to date.

I. REPRESENTATIVE MINING OPERATIONS

A. Coal Rank: The coals in the Raton Mesa region have been upgraded by abnormally high heat flow from igneous intrusions. In some places the coals have even been naturally coked. Much coal of coking quality is now found in the Trinidad coal field in Las Animas County. Overall in the region, the coals are medium- and high-volatile bituminous.

B. Minimum Leasehold Requirement: The design annual production capacity for the smallest of the major mines, those mines producing at least 0.1 million tpy, is 0.5 million tpy. The thickest beds in this region are about 10 ft thick, and it is in the thicker beds that mining has been concentrated. These conditions, along with an estimated minimum mine life of 20 years and an underground recovery factor of 50%, indicate that the minimum leasehold required should be about 1,100 acres. Where multiple beds are mined or the annual production rate is lower, the acreage required will be proportionally less.

C. Minimum Recoverable Reserves Requirement: For a mine producing 0.5 million tpy for 20 years, the recoverable reserves would be 10 million tons.

D. Mine Life: 20 to 30 years, although some mines may operate for longer periods. The CF&I Steel Corporation's Allen mine may have reserves sufficient for a total of 40 years.

E. Coal Price, FOB Mine: Recent spot market prices for coal from Colorado with less than 0.75% sulfur range from $17 per ton for coal with 10,500 Btu/lb to $20 per ton for coal with 11,500 Btu/lb.

F. Design Capacity: In the past, mines in the Raton Mesa region each have produced an average of 0.67 million tons over the course of their lives. In the future, this value will be typical of annual production, according to current plans. As in the past, however, there may still continue to be some very small mines with local markets that contribute marginally to the output of the region.

Currently, only three mines, with annual capacities of at least 0.1 million tons, are planned for the Raton Mesa region for the coming decade. All three will be in the production range of from 0.5 to 0.9 million tons per year. Two of these mines will be underground, and the third will be a combined surface and underground operation, the only one now planned in the State.

G. Mining Technology: The current surface and underground mines use standard techniques. The underground mines use continuous miners. In the future some of the underground mines may be large enough, producing more than about 0.7 million tpy, to effectively use longwall techniques.

H. Capital Requirements: An underground mine producing about 1 million tpy currently costs about $35 to $40 million.

I. Labor Requirements: The Allen mine of the CF&I Steel Corporation, which has been producing for years and which is typical, in terms of size and methods, of mines anticipated in the future, has used somewhat more than 400 employees to produce about 0.6 million tpy for the past few years. However, the productivity of this mine is considered to be lower than average for the State.

J. Surface Equipment: Underground mines will require typical surface facilities such as coal handling, loading, and storage facilities, haul roads and railroad lines, and offices. Such facilities would also be required for surface mines, in addition to the usual surface mining equipment.

K. Proximity to Transportation: The Raton Mesa region is served by several railroads, as well as by State and Federal highways.

L. Common Transportation Mode: Coal is shipped by trucks and unit trains. Additionally, a coal slurry pipeline from Walsenburg, Colorado, to Texas has been proposed.

M. Community Infrastructure Requirements: There are several well established communities in the region, including Trinidad and Walsenburg, which have supported coal mining operations for years, and which are probably adequate to support the modest development that is currently planned.

II. GENERAL MINING CONDITIONS

A. Structural Attitudes: The Raton Mesa coal region lies in the Raton structural basin, which is an asymmetric, southward-plunging syncline with its axis west-of-center. The beds dip gently on the east but dip steeply and are locally overturned on the west. The structure is further complicated by igneous intrusions that have penetrated the center of the basin and by faulting, particularly along the western flank. The beds that have been recently mined range in dip from 1° to 16°.

B. Topographic Relief: The region is of moderate relief, with mesas and stream-cut valleys that are typical of this relatively high, semi-arid foothills region.

C. Maximum Overburden: Coals are present, in the deepest part of the basin, at depths below 3,000 ft. Recently, surface mines have operated in areas with no more than 60 ft of overburden, while underground mines have operated under 400 ft to 1,400 ft of overburden.

D. Market: Most of the coal that has been produced in recent years has been mined by the CF&I for use in its steel mill in Pueblo, Colorado, about 150 miles north of the Raton Mesa region. Coal from the other mines generally is used locally. One proposed mine would supply coking coal to Eastern steel mills.

III. TYPICAL COAL BED CHARACTERISTICS

A. Analyses, As Received: Typical analyses are shown in Table 7.

B. Thickness of Coal: Coal beds in this region are generally less than 10 ft thick.

C. Mining Problems: These include roof stability, naturally coked coal, igneous sills and dikes, and some methane gas in coal beds, especially in the higher rank coals.

TABLE 7

Range of Analyses of Coals from the Raton Mesa Region (As-Received)

Field and Beds	Moisture %	Volatile Matter %	Ash %	Sulfur %	Heating Value Btu/lb
Trinidad, Raton Fm.					
(~11 beds)	1.8-4.5	34.4-40.3	5.3-16.4	0.4-1.1	10,169-13,871
Vermejo Fm. (14 beds)	1.6-7.5	32.2-39.1	7.7-21.8	0.5-1.0	11,430-13,510
Walsenburg					
Raton Fm.	2.5-4.2	--	5.3-13.5	0.4-1.0	12,660-13,340
Vermejo Fm.	5.3-10.2	36.4-38.0	7.2-14.4	0.4-1.3	11,050-12,880

SAN JUAN RIVER REGION

The San Juan River coal region is located in southwest Colorado and in part of west-central Colorado as far north as the Grand Valley-Grand Junction area and the southern part of Delta County. The larger part of this region lies in northwest New Mexico and includes the San Juan structural basin, the Red Mesa-Mesa Verde platform, the Cortez saddle, and the eastern part of the Paradox basin, which extends into Utah. The region also includes parts of the Gunnison and Uncompahgre uplifts in Colorado. There are four named coal fields in the San Juan River region in Colorado.

The Durango Coal field includes the Colorado portion of the San Juan structural basin, the Hesperus-Red Mesa-Cortez area, and the Mesa Verde area, in La Plata and Montezuma Counties. Coals in the field are found in the Dakota Sandstone (or Formation), Menefee Formation, and Fruitland Formation.

The Dakota coals are relatively thin, discontinuous, and of high ash content in and near the areas of outcrop (the Hogback) north and northeast of the town of Durango. To the south and west, in the subsurface, Dakota coals have been mined to some extent at relatively shallow depths; a deeper resource exists to a depth of 8,000 ft or more in the Colorado portion of the San Juan basin.

Coal beds in the Menefee Formation comprise the most significant coal resource in the Durango field and are the only ones being mined at present. In local areas of structural complexity near Durango, they are of coking quality.

To date, La Plata and Montezuma Counties have produced more than 6.76 million tons of coal, which is more than 75% of the total for the entire San Juan River region. Production during 1978 from three small underground mines and one surface mine in La Plata County totaled less than 80,000 tons.

Nucla-Naturita Coal field, in the broad sense, extends from Dolores County northward to just south of the Colorado River, in Mesa County. Throughout this large, highly dissected area, most of the post-Dakota coal-bearing rocks, and even much of the Dakota Sandstone itself, have been stripped away by erosion. The single currently producing mine in this field, Peabody Coal's Nucla multiple-bench surface mine, furnishes approximately 102,000 tons of coal per year to the nearby Nucla power plant (capacity, about 37 MW). The Nucla-Naturita coal field to date has produced over 2.1 million tons of coal, or about 24% of the total for the San Juan River region.

Pagosa Springs Coal field, located in Archuleta County, has produced a total of only about 140,000 tons of bituminous coal over the years. The lone operating mine in the field, the Martinez, which opened in 1977, surface-mined 35,204 tons of coal during 1978.

Tongue Mesa Coal field, which had been placed within the Uinta region by others, herein is included within the San Juan River region. Although not shown as such on some recent maps, the Tongue Mesa field consists of an isolated erosional remnant of Upper Cretaceous sediments (equivalent to at least part of the Mesaverde Group) capped by volcanic rocks of Late Cretaceous and early Tertiary ages. The field is located on Cimarron Ridge, about 20 miles southeast of the town of Montrose and 8 miles east of U.S. Highway 550, and it straddles the Montrose County-Ouray County line. The coal-bearing "Mesaverde" sequence has been eroded west of Tongue Mesa field.

The coals in this field occur within a 900-ft-thick sequence that correlates with the Kirtland-Fruitland-Pictured Cliffs Formations in the San Juan basin to the south. At least four coal beds occur on Tongue Mesa in the lower 200 ft of the Fruitland Formation. The most persistent and the thickest coal bed here, the Cimarron (or Lou Creek), together with several thinner coals, have been underground-mined intermittently from the 1890's until the 1940's. No mines presently are active in the field.

Since the late 1800's, the San Juan River region has produced slightly more than 9 million tons of coal (from nearly 200 mines), which represents about

1.4% of the total for Colorado. In 1978, the region produced 217,694 tons of bituminous coal from three underground and three surface mines; this is approximately 1.5% of the total State production.

I. REPRESENTATIVE MINING OPERATIONS

A. Coal Rank: Data are generally unavailable for the region as a whole, except for the mined areas. Coals in the Tongue Mesa coal field are generally subbituminous B in rank. Coals from the other fields are generally reported as bituminous. In the Durango coal field, they are high-volatile A or B bituminous and locally are suitable for coking.

B. Minimum Leasehold Requirement: Most recently active mines have annual production rates of less than 0.1 million tons per year (tpy), and anticipated lives of anywhere from several years to 30 years. The smallest mines may require leaseholds of only a few tens of acres. There is only one substantially larger mine planned for the region, an underground mine to produce up to 1 million tpy. A mine this large, with a life of 20 years, a recovery factor of 50%, and a bed of bituminous coal 10 ft thick (about the thickest presently being mined), would require a leasehold of about 2,200 acres.

C. Minimum Recoverable Reserves Requirement: For very small mines, the recoverable reserves required could be less than 1 million tons. For the large underground mine described above, the reserves required would be about 20 million tons.

D. Mine Life: Mines with a capacity of 100,000 tpy or less may produce from several years to 30 or more years. Larger mines will probably produce at least 20 years.

E. Coal Price, FOB Mine: Recent spot market prices for coal from Colorado with less than 0.75% sulfur range from $17 per ton for coal of 10,500 Btu/lb to $20 per ton for coal of 11,500 Btu/lb.

F. Design Capacity: Most mines in the region currently are producing less than about 0.1 million tpy. The only larger mine planned for the region will have a design capacity of 1 million tpy. The statewide trend in mine sizes is shown in Tables 1, 2, and 3.

G. Mining Technology: Current mines use a variety of standard mining techniques. Underground mines use conventional and continuous-mining techniques. Surface mines use backhoes, bulldozers and scrapers, and draglines.

H. Capital Requirements: Surface mines producing 1.0 million tpy require $15 to $20 million (±20%) in capital. Underground mines of about the same capacity require $35 to $40 million (±20%) in capital.

I. Labor Requirements: For the small mines producing in recent years the average annual productivity of employees has ranged from 1,018 tons to 5,832 tons, with an average of 3,641 tons, for surface mines; and ranged from 609 tons to 1,525 tons, with an average of 1,175 tons, for underground mines. The projected larger underground mine will probably be able to produce at a higher rate per employee.

J. Surface Equipment: Both surface and underground mines will require railroad spurs and haul roads; offices; and coal handling, loading, and storage facilities.

K. Proximity to Transportation: This part of Colorado is poorly served by railroads. The very northern parts of the region are served by a spur of the Denver and Rio Grande Western Railroad which extends south to Montrose. Another spur of this railroad extends westward to Creede, east of the eastern part of the region. There are numerous State highways in the San Juan River region, but the lack of access to railroads in most of the area is an impediment to the large-scale development of its coal resources.

L. Common Transportation Mode: Currently coal is trucked to local consumers or to railroad lines at distances of up to 140 miles.

M. Community Infrastructure Requirements: This large region includes numerous communities that have supported low levels of coal mining in the past and that can probably support the anticipated low level of development without undue strain.

II. GENERAL MINING CONDITIONS

A. Structural Attitudes: The beds currently mined dip from 1° to 5°.

B. Topographic Relief: Ranges from moderate to severe, depending upon proximity to the San Juan Mountains. Much of the region consists of highly dissected plateaus, cut by numerous streams and rivers. Steep-sided valley walls provide convenient access for drift mining in many parts of the region.

C. Maximum Overburden: Overburden in surface mines range up to 70 ft, while overburden in underground mines range from 1,500 ft to 1,300 ft. Some coals are buried up to 8,000 ft in the Colorado part of the San Juan basin.

D. Market: Most coal produced in this region is used locally because of the problems of shipping coal outside of the area. Local users include small industries, the Nucla electric power plant, private and State institutions, and households. Some coal is shipped to other parts of Colorado and out-of-state for industrial use.

III. TYPICAL COAL BED CHARACTERISTICS

A. Analyses, As-Received: Analyses of the coal from the San Juan River region are summarized in Table 8.

B. Thickness of Coal: The beds that have recently been mined range from 1 ft to 12 ft in thickness. Most of these beds are 5 ft to 10 ft thick, but in some areas there are multiple beds with aggregate thicknesses of more than 20 ft. In the Tongue Mesa coal field, the maximum thickness of coal may be as much as 40 ft.

TABLE 8

Range of Analyses of Coal from the San Juan River Region (As-Received)

Field and Bed	Moisture %	Volatile Matter %	Ash %	Sulfur %	Heating Value Btu/lb
Durango					
Fruitland Fm.	0.9-2.3	20.8-23.6	19.5-26.6	0.7-0.8	11,230-12,140
Menefee Fm. (9 beds)	1.6-10.7	36.2-42.1	3.4-16.6	0.6-1.3	10,860-14,700
Nucla-Naturita					
Dakota Ss. (Fm.) (3 beds)	2.5-13.5	32.6-36.1	6.1-12.8	0.5-1.1	10,010-13,380
Tongue Mesa					
Fruitland Fm. (Cimarron)	14.2-16.0	36.0-47.3	6.7-8.4	0.5-0.9	9,350-10,200

C. Mining Problems: In parts of the region, rugged topography may create problems in mining. The thinness and relatively high ash content of some of the coal beds in the area can present problems, particularly in multi-bench surface mining operations (as at Nucla). Additionally, some areas in the Tongue Mesa area have wilderness values which could conflict with mining developments.

UINTA REGION

Approximately one-half of the large Uinta coal region lies in west-central Colorado; the remainder constitutes the main coal-bearing region of eastern Utah. Most of that part of the region located in Colorado coincides with the Piceance Creek structural basin of Laramide age and is located in the eastern part of the Colorado Plateau physiographic province. The Uinta region in Colorado is bounded by the Grand Hogback monocline on the east, Axial Basin uplift on the north (which separates this region from the Green River coal region), the Utah State line on the west, Grand Valley and the Colorado River on the southwest, and the North Fork Valley and Gunnison uplift on the south and southeast.

The Piceance Creek basin is the largest structural basin in western Colorado, covering an area exceeding 7,200 square miles, as defined by the base of the Upper Cretaceous Mesaverde Group. The basin is asymmetric in shape, with the steep flank on the east; its long axis trends northwest. This is one of the deepest basins in the Rock Mountain region, with an estimated 25,000+ ft of sediments filling its deepest part, which is located at the north end of the basin, in Rio Blanco County. The southeastern part of the region, in Gunnison and Pitkin Counties, is marked by the Elk and West Elk Mountains igneous intrusive complexes of Tertiary age -- sills, laccoliths, dikes, etc., and associated folds and faulting. The high geothermal heat flow characteristic of this part of the region has increased the rank of much of the coal that occurs here. As a result, the southeast part of the Uinta region contains large resources of coking coal, much of it of premium grade and high in methane content; and commonly under more than 1,000 ft of overburden.

The eight coal fields in the Uinta region that exist around its periphery are briefly discussed below in alphabetical order. All of these fields are, or have been, productive from the Mesaverde Group. The Lower White River field is the only one not presently producing; however, several companies have been conducting exploration in the area that may result in the opening of one or more coal mines within the next few years. The Uinta coal region produced nearly 3 million tons of coal in 1977, one-fourth of the State's total output; 1978 production in the region was more than 3.187 million tons, most of it (77%) from underground mines. Since the late 1800's, this important region has produced more than 91.5 million tons of coal, which constitutes nearly 15% of the total for all of Colorado, from nearly 300 mines. Currently, the Uinta region is second only to the Green River region in annual production, and first in the State in the production of both underground-mined coal and coking coal.

Book Cliffs field contains a number of high-quality coal beds in the Mount Garfield Formation of the Mesaverde Group. Estimated total in-place resources in this field (in the 800-square-mile area considered) are approximately 7.2 billion tons to a depth of 6,000 ft. During 1978, approximately 533,000 tons of coal were produced from the Book Cliffs field, all from underground mines -- five in Garfield County and one in Mesa County.

Carbondale field, located at the eastern edge of the region, in Garfield and Pitkin Counties, produces high-quality coking coal from the Mesaverde Group. Original in-place coal resources to a depth of 6,000 ft in the 165-square-mile area considered have been estimated at more than 5.2 billion tons. In 1978 the Carbondale field produced 916,811 tons of coal, all but 500 tons from seven underground coking coal mines in Pitkin County.

Crested Butte field is located at the southeastern tip of the Uinta region, in Gunnison County, near the Crested Butte ski resort. Much of the field lies at elevations above 10,000 ft. Coal-bearing Mesaverde strata in this area have been folded, faulted, and intruded by igneous rocks. Original in-place coal resources, to a depth of 6,000 ft, in the 240-square-mile area surveyed, are estimated at some 1.56 billion tons. A small amount of steam coal was produced from one underground mine in the field during 1978.

Danforth Hills field, which extends from Axial south to Meeker, is situated at the northeast limit of the Uinta region, in Rio Blanco and southern Moffat Counties. This field is separated from the Yampa field, Green River region, to the north by Axial Basin, a topographic low in which the coal-bearing Mesaverde Group, which crops out in hills both to the north and south, has been stripped away. Both subdivisions of the Mesaverde Group here, the Iles and Williams Fork Formations, contain numerous good-quality bituminous coal beds. Original in-place coal resources to a depth of 6,000 ft, in the approximately 400 square miles for which the estimate was made, total more than 10.5 billion tons. More than 1.14 million tons of coal were produced from the Danforth Hills field in 1978, a significant increase over the 0.3 million tons produced during 1977. The old Rienau No. 2 underground mine, in Rio Blanco County, was reopened by Northern Coal Co. late in 1977 and produced 36,001 tons in 1978.

Grand Hogback field is located along the east rim of the Piceance Creek basin, the edge of which is sharply upturned to form the prominent Grand Hogback monocline. This feature extends south of Meeker for some 40 miles to Rifle, then makes an abrupt bend to the southeast, through the old mining town of New Castle, where the hogback is cut through by the Colorado River, then to Glenwood Springs, where the structure again trends south, marking the eastern edge of the Uinta region. Coal-bearing Mesaverde sediments crop out along the length of the Grand Hogback, with its 40° to near-vertical dips, where coal has been mined for many years. The major part of the coal mined from this field has come from the "Fairfield" and "South Cañon" coal "groups" or "zones" in the lower part of the Williams Fork Formation. The "Black Diamond" coal group, in the upper part of the Iles Formation, also has been mined in this area, as has the "Keystone" coal group, in the upper part of the Williams Fork. Original in-place resources to a depth of 6,000 ft in the 160-square-mile area considered are estimated at more than 3 billion tons. Two small "one-man" underground mines produced slightly more than 500 tons of coal from steeply dipping Mesaverde beds during 1978.

Grand Mesa field, situated on the south flank of the prominent Grand Mesa, a very large flat-topped feature over 10,000 ft in elevation that is capped by Tertiary volcanic flows, lies primarily in Delta County. The northwestern part of the field, on the west flank of Grand Mesa and south of the Colorado River, is located in Mesa County. The Mesaverde coals in this field are in the Mt. Garfield Formation, much the same as are coals in the Book Cliffs field. The coal beds in Grand Mesa field range from high-volatile C bituminous to subbituminous A and are typically 4 to 14 ft in thickness. Original in-place resources, to a depth of 6,000 ft, in the 530-square-mile area for which the estimate was made, probably exceed 8.6 billion tons. Two small mines, one surface and one underground, located in Delta County, produced 41,656 tons of bituminous steam coal in 1978.

Lower White River field covers a large area that includes the western Piceance Creek basin and much of the Douglas Creek arch, westward to the Utah State line. Most of the field lies in Rio Blanco County; a small part, a few miles north of the giant Rangely oil field (the largest field in Colorado), is located in southern Moffat County. Coals in Lower White River field are in both the Williams Fork and Iles Formations. Most of the mining to date has taken place in the Rangely area, in the Mesaverde rimrock that defines the flanks of the large, breached Rangely anticline. In the 930-square-mile area surveyed, 11.76 billion tons of in-place coal resources have been estimated to a depth of 6,000 ft. No coal mining has taken place in Lower White River field for a number of years, although new mining activity reportedly is being planned by at least one company.

Somerset field is located in the valley cut by the North Fork of the Gunnison River and its tributaries, in Delta and Gunnison Counties. The coals in this area occur in the Bowie and Paonia Members of the Williams Fork Formation. In the eastern part of the field, near the settlement of Somerset, coking coal of relatively good quality is produced at mines that include U.S. Steel's Somerset mine, the largest underground mine in Colorado (present capacity, approximately 1 million tons per year). More than 1.2 million tons of coking coal were produced from three underground mines in the field during 1978. In-place coal resources to a depth of 6,000 ft in the 320-square-mile area investigated are conservatively estimated at more than 8 billion tons.

I. REPRESENTATIVE MINING OPERATIONS

A. Coal Rank: The rank of coal in the Uinta Region, by field, is as follows:

1. Book Cliffs Field: Mostly high-volatile C bituminous, with some high-volatile B bituminous.

2. Carbondale Field: Medium-volatile bituminous, high-volatile A bituminous, semi-anthracite, and anthracite.

3. Crested Butte Field: High-volatile C bituminous to anthracite, some good coking-quality coal.

4. Danforth Hills Field: Good-quality bituminous coal, mostly high-volatile C.

5. Grand Hogback Field: Mostly high-volatile C bituminous, grading southward to high-volatile B bituminous.

6. Grand Mesa Field: High-volatile C bituminous to subbituminous A.

7. Lower White River Field: High-volatile C bituminous.

8. Somerset Field: High-volatile B and C bituminous.

B. Minimum Leasehold Requirement: Of the 17 mines expected to be producing at least 0.1 million tons per year (tpy) in the Uinta region through the next decade, the smallest underground mine will have a production rate of 0.2 million tpy, and the smallest surface mine will have a production rate of 0.4 million tpy. If these mines have lives of at least 20 years, and if the underground recovery rate of 50% is only somewhat more than half of the recovery rate of surface mines, then the minimum reserves for both surface and underground mines should be approximately 8 to 9 million tons. The thickest coal beds in most fields in the Uinta region are 10 ft to 20 ft thick. For the mining of such beds, minimum leasehold requirements would be a few hundred acres, depending on the thickness of the beds. There are thicker beds in some fields and thinner beds in all of the fields, so that the leasehold requirement could vary considerably from this factor alone.

C. Minimum Recoverable Reserves Requirement: The minimum recoverable reserves for major surface and underground mines in this region are probably 8 to 9 million tons.

D. Mine Life: 15 to 30 years, although some mines may produce for longer periods.

E. Coal Price, FOB Mine: Recent spot market prices for coal from Colorado with less than 0.75% sulfur range from $16 per ton for coal of 10,500 Btu/lb to $20 per ton for coal of 11,500 Btu/lb.

F. Design Capacity: The annual productive capacities of major surface and underground mines that will be producing over the next decade vary as widely in the Uinta region as in any coal-producing region in Colorado. Indeed, the Uinta region is the site of both the largest surface and underground mines planned for the State. The planned annual productive capacities of surface mines range from 0.4 to 4.3 million tpy, but most will produce between 1.0 and 2.9 million tpy (Table 2). The planned annual productive capacities of underground mines range from 0.2 to 1.6 million tpy, and most of these mines will be smaller than 0.5 million tpy or larger than 0.9 million tpy (Table 3).

G. Mining Technology: Standard surface and underground mining techniques will probably be used in this region. Conventional, continuous mining, and longwall mining techniques are being employed in underground mines in the region.

H. Capital Requirements: For an underground mine of 1-million-tpy capacity, \$35-\$40 million (±20%) is required. For a surface mine of similar capacity, \$15-\$20 million (±20%) is required.

I. Labor Requirements: For large underground mines, productivity in recent years has ranged from 934 tons per employee per year to 4,185 tons per employee per year, with an average of 2,149 tons per employee. Statistics are not available for surface mines, but employee productivity is generally substantially higher in surface mines than in underground mines. Because this region has some of the largest surface mines in the State, it may also have some of the highest employee productivities, although these mines will still require a larger than average number of employees.

J. Surface Equipment: Both surface and underground mines will require such facilities as coal loading, storage, and handling facilities, railroad spurs and haul roads, and offices. Surface mines will require the usual large surface mining equipment, such as draglines, shovels, and trucks.

K. Proximity to Transportation: The Uinta region is served by a main and a branch line of the Denver and Rio Grande Western Railroad, as well as by State and Federal highways.

L. Common Transportation Mode: Coal is transported short distances by truck to nearby rail-loading facilities or to the consumer. Coal is shipped longer distances by unit trains.

M. Community Infrastructure Requirements: There are some established communities in this region, including Grand Junction. Because of the long history of mining in this area, there may be a relatively good supply of trained manpower available.

II. GENERAL MINING CONDITIONS

A. Structural Attitudes: The part of the region lying in Colorado coincides with the deep Piceance Creek structural basin, which is elongate in a northwest direction and asymmetric in cross-section, with its steep flank on the east. The structure in parts of the region, especially around its margins, is complicated by igneous intrusions, faults, and folds. Bed dips vary widely, from nearly flat-lying to near-vertical, especially around the periphery of the basin.

B. Topographic Relief: Parts of this region are extremely rugged and mountainous, with elevations ranging up to some 14,000 ft. Other parts consist of steep-sided stream and river valleys and high plateaus. Much of the underground-minable coal is accessible via drift mining from valley walls.

C. Maximum Overburden: Currently operating surface mines are mining in areas with as much as 300 ft of overburden. Underground mines have or will operate in areas with overburden ranging from 60 ft to 3,000-plus ft, although most presently operating mines are in areas with 2,000 ft or less of overburden.

D. Market: Many mines in this area produce steam coal for use in Colorado. Metallurgical coal is a major product from this area, supplying steel mills in Colorado, Utah, and California, and which may supply Asian markets in the future. Steam coal from this region is or has been shipped to such states as Texas, Arizona, Mississippi, and Indiana. Additionally, some industrial coal has been supplied to eastern Colorado and to Texas.

III. TYPICAL COAL BED CHARACTERISTICS

A. Analyses, As-Received: Analyses are summarized in Table 9.

TABLE 9

Range of Analyses of Coal from the Uinta Region (As-Received)

Field and Beds	Moisture %	Volatile Matter %	Ash %	Sulfur %	Heating Values Btu/lb
Book Cliffs					
Mt. Garfield Fm. (Mesaverde Gp.) (Carbonera, Cameo, Palisade, Thomas, Anchor Mine)	3.3-14.0	29.8-35.4	4.9-23.3	0.4-1.7	9,833-13,560
Carbondale					
Williams Fork Fm. ("South Cãnon Gp.," Dutch Creek, Allen, Anderson)	0.8-3.4	22.0-28.1	3.4-10.0	0.3-1.3	12,470-15,190
("Fairfield Gp." or A,B,C,D, Coal Basin A-B)	0.8-4.0	21.8-39.3	3.4-6.7	0.4-1.5	12,609-15,088
Crested Butte					
Williams Fork F., Paonia Mbr. (6 beds)	2.5-13.3	--	3.2-9.1	0.4-1.9	11,400-14,170
Danforth Hills					
Williams Fork Fm. (Lion Cyn., Goff, Fairfield Gps.)	8.9-15.5	--	2.2-9.6	0.3-1.4	10,140-11,790
Iles Fm. ("Black Diamond Gp.")	9.2-13.4	--	3.7-10.0	0.4-0.6	11,300-11,970
Grand Hogback					
Williams Fork Fm. (E, Sunnyridge)	4.0-4.8	37.2-39.8	6.1-10.4	0.6-0.7	12,060-12,581
Grand Mesa					
Mt. Garfield Fm. (Mesaverde Gp.) (6-8 beds)	3.1-19.5	30.4-35.0	2.1-17.9	0.5-2.2	8,298-13,489
Lower White River					
Williams Fork Fm.	11.2-14.1	--	4.4-8.5	0.4-0.5	10,800-11,230
Somerset					
Williams Fork Fm. (F,E,D,C,B,A beds)	3.2-13.6	35.3-37.7	3.2-11.4	0.5-0.8	10,040-13,453

B. Thickness of Coal: The thicknesses of coal beds, by fields, are as follows:

1. Book Cliffs Field: General data are unavailable; recently mined beds are 6 ft to 9 ft thick.

2. Carbondale Field: General data are unavailable; recently mined beds are 1 ft to 10 ft thick, but mostly at least 6 ft thick.

3. Crested Butte Field: 2 ft to 14 ft.

4. Danforth Hills field: Up to 20 ft or more.

5. Grand Hogback Field: 3 ft or more.

6. Grand Mesa Field: Typically 4 ft to 14 ft.

7. Lower White River Field: Typically 8 ft to 12 ft or more.

8. Somerset Field: Up to 25 ft to 30 ft.

C. Mining Problems: These are generally site-specific and can include gassy coal beds, heaving floors, roof problems, coal "outbursts," sandstone dikes, faulting, and problems due to steep dips.

CRITERIA FOR CHARACTERIZING COAL MINES IN THE WESTERN UNITED STATES

CONVENTIONAL MINE DEVELOPMENT MODEL

MONTANA

GENERAL STATEMENT

The coal fields of Montana underlie about 35 percent of the area of the state, mostly in its eastern two-thirds. Most of the coal is found in five widespread formations ranging in age from Late Jurassic to Eocene. The beds being mined range in thickness from about 4 to more than 50 ft, although most of the principle seams at current mining operations are 10 to 30 ft thick. For purposes of estimating coal reserves, the U.S. Geological Survey has established a regional recovery factor of 85 percent for surface mining methods.

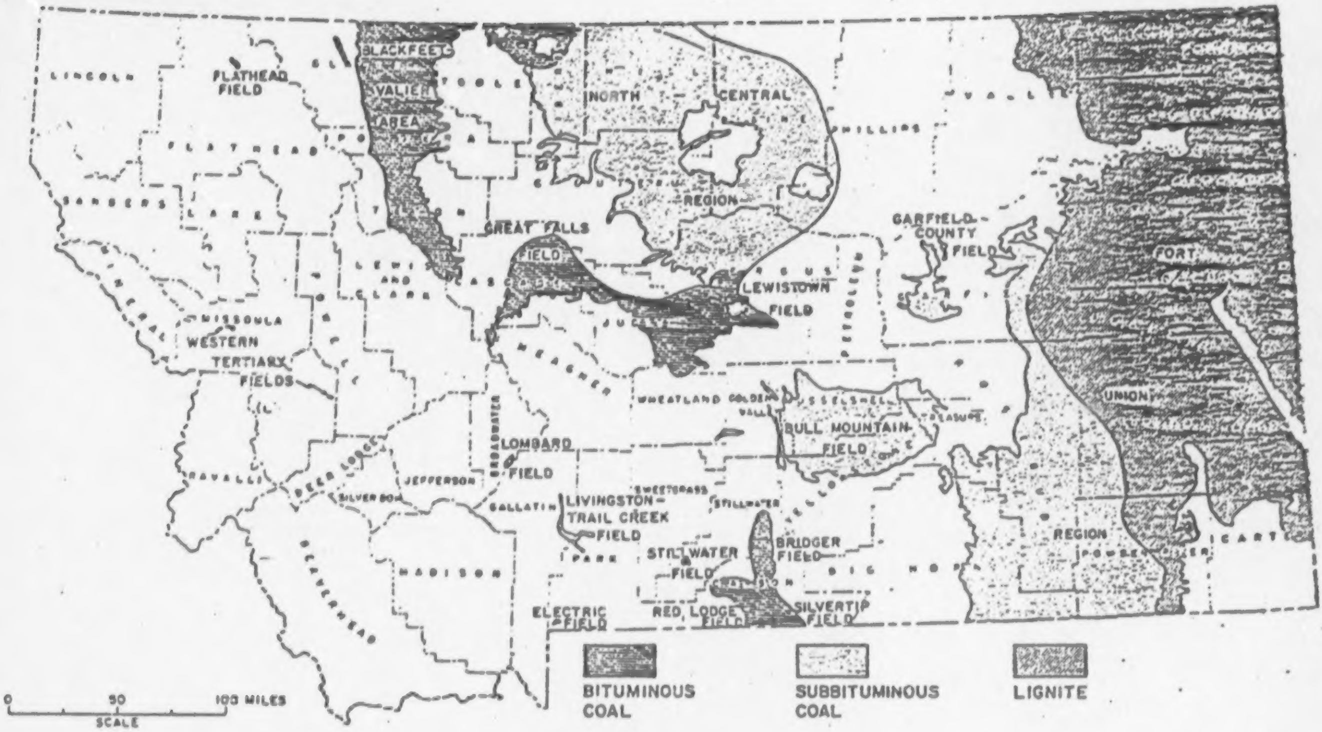
Mining Method: At this time, all major production is by surface-mining methods, typically using draglines. Almost all proposed or projected coal mines in the state are surface mines. However, there are deep coal resources suitable for underground mining, and there is at least one new underground mine with a full capacity of 1 million tons per year.

Mine Size: Coal production from important mines for 1978 ranged from a low of 8,000 tons for the Divide Mine at Roundup to a high of 10.5 million tons for the Rosebud Mine at Colstrip. Five of the state's nine largest mines produced over 1 million tons during 1978. The trend is toward mines that will produce at least 1 million tons/year, and by 1985 most of the proposed new or expanded mines will be producing from 5 to 20 million tons per year.

Utilization: Currently, virtually all of Montana's coal is used for the steam generation of electric power, and this is the anticipated use for most, if not all, of the coal for the next several years. A minor amount is used by industry. In the future, some of the coal probably will be used by coal conversion plants, if such plants are developed.

Future Potential: The potential for future production of coal in Montana depends primarily upon demand from out-of-state. Over the past several years more than 95 percent of the fuel used by steam-electric plants in Montana has been coal. Some of the existing plants will be expanded, and at least two new coal-fired plants are planned, as is a coal liquefaction plant. However, Montana's coal production in the past has greatly outstripped the in-state demand for coal, and planned future production should readily outstrip anticipated increases in in-state demand.

Montana


BLACKFEET
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PETROLEUM
GARFIELD
COUNTY
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UNION
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POWDER RIVER
CARTER
LINCOLN
FLATHEAD
FIELD
FLATHEAD
SANDERS
LAKE
LEWIS AND CLARK
MINERAL
MISSOULA
WESTERN
TERTIARY
FIELDS
MEAGHER
WHEATLAND
GOLDEN VALLEY
BULL MOUNTAIN
FIELD
BROADWATER
LOMBARD
FIELD
RAVALLI
DEER LODGE
SILVER BOW
JEFFERSON
GALLATIN
LIVINGSTON-
TRAIL CREEK
FIELD
SWEETGRASS
STILLWATER
PARK
STILLWATER
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BRIDGER
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BIG HORN
CARBON
MADISON
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ELECTRIC
FIELD
RED LODGE
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SILVERTIP
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0
50
100 MILES
SCALE
BITUMINOUS COAL
SUBBITUMINOUS COAL
LIGNITE

Index Map of Montana Coal Fields

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COAL CHARACTERISTICS

Rank: Lignite is found in easternmost Montana in the northern and southern parts of the Fort Union coal region, including the western Williston basin and the eastern edge of the northern Powder River basin. Subbituminous coal is found along a northwest-southeast trend that includes most of the northern Powder River basin, in the southwestern part of the Fort Union coal region, the Blue Mountain and Garfield County fields, and the North Central coal region. Bituminous coal is found along a parallel trend farther west, including the Blackfeet-Valier area; and the Great Falls, Lewistown, Stillwater, Bridger, Silvertip, and Red Lodge fields. Bituminous and subbituminous coal are both found in smaller, intermontane fields farther west.

Sulfur Content: In the Fort Union coal region, where the coal has been extensively analyzed, the sulfur content, on an as-received basis, ranges from 0.11 to 1.63 percent, but it is most commonly between 0.30 and 0.60 percent. These values are typical of the coal being mined in the area. In the northern Powder River basin, typically most of the sulfur is organic, but a significant part is pyritic. In other areas, the coal has been less extensively analyzed.

The apparent sulfur content of coal in several other areas is as follows: Bull Mountain field, 1.0 percent; Red Lodge field, 1.0 to 1.3 percent; Great Falls-Lewiston region, 1.7 to 4.0 percent; Livingston-Trail Creek region, 0.6 percent; and the Lombard field, 8.2 percent. Analyses are not available for other coal fields in Montana.

Heating Values: In the Fort Union region, the heating values range from about 5,830 to about 10,190 Btu per pound on an as-received basis. The coal presently being mined in that area has heating values above 8,000 Btu per pound. In areas farther west, for which fewer analyses are available, the heating values appear to range generally from 9,000 to 11,000 Btu per pound on an as-received basis.

Moisture Content: In the northern Powder River basin, the moisture content ranges approximately from 13 to 42 percent. Most values fall between 20 to 30 percent, but a substantial proportion of the values are higher. The values of coal currently being mined in this area average about 25 percent. Data for other areas are not available. However, in light of the variety of geologic conditions under which coal is found in Montana and the variability of other factors of coal quality within the state, it is probable that the moisture contents of the coal in these areas vary considerably.

Volatile Matter: Statewide data are not available. In the northern Powder River region, the content of volatile matter, on an as-received basis, ranges approximately from 21 to 40 percent, although for most coals it is between 26 and 33 percent.

Ash Content: In the Fort Union region, the ash content of coal ranges from 3.8 to 10.7 percent on an as-received basis. Most values are below 8 percent. The coal currently mined in this area reflects the full range of ash content. In other areas, the ash content is generally less well known. It appears to be about 7.5 percent in the Bull Mountain field, 13.4 percent in the Red Lodge field, 11.5 percent in the North Central region, 8 percent in the Livingston-Trail Creek region, and 29 percent in the Lombard field. In the Great Falls-Lewistown field, the ash content appears to vary widely. For other areas, the ash contents have not been reported.

COAL CONVERSION

Gasification: Most of the coal in Montana is subbituminous or lignite in rank and, therefore, is suitable for the Lurgi low-Btu gasification process. The higher ranking coals in Montana, including a few coals that have been used for coking, may be suitable for methanation.

Liquefaction: The bituminous coal in the western part of the coal-bearing regions of the state may be suitable for liquefaction. The Crow Indians are planning a coal liquefaction plant, which they hope will be one of the first in the nation, to be located on the reservation southeast of Billings, Montana.

FORT UNION COAL REGION

NORTHERN POWDER RIVER BASIN AREA

The northern Powder River basin part of the Fort Union region contains about 32,000 million tons of strippable reserves, more than 60% of the total strippable reserves of the State of Montana. Production in 1978 from the northern Powder River basin exceeded 25,500,000 tons, which accounted for more than 98% of the estimated total production of the State. All of the current production from this area is by surface mining, although there are extensive underground-minable reserves. Virtually all of the coal is used for steam generation of electric power. Most existing and proposed mines are near existing or proposed railroad lines and spurs, although large areas of the field are several tens of miles from existing railroad service.

I. REPRESENTATIVE MINING OPERATIONS

Although there are underground-minable reserves in this area, the preponderance of surface-minable coal directs that only surface mines should be considered in this model. The minimum requirements addressed below should be recognized as nothing more than minimum requirements. Most ongoing and planned operations will be at a scale considerably larger than minimum.

A. Coal Rank: Most subbituminous, although lignite occurs in the eastern part of the basin, and bituminous coal occurs in some of the deeper beds in the central part of the basin.

B. Minimum Leasehold Required: Varies widely because of the approximately 10-fold variation in thickness of potentially minable beds. The minimum leasehold required for mining of the thickest beds is probably a few hundred acres, with requirements increasing to 1,000 to 2,000 acres for the mining of thinner beds.

C. Minimum Recoverable Reserves Required: 20 to 30 million tons, assuming a basin-wide recovery factor of 85%.

D. Mine Life: 20 to 30 yr.

E. Coal Price, FOB Mine: Estimated \$6 to \$8/ton, current.

F. Design Capacity: 1 to 20 million tons per year (tpy); most proposed mines are about 5 million tpy or larger.

G. Mining Technology: Most current operations depend on draglines, but some use shovels for stripping, as well.

H. Capital Requirements: \$15 to \$20 million (±20%) for a 1 million tpy mine.

I. Labor Requirements: 100 or fewer to 300 or more employees for mines ranging in production from about 1 to 10 or more million tpy.

J. Surface Equipment: For mining, standard surface-mining equipment, including draglines, stripping and loading shovels, scrapers, dozers, front-end loaders, and trucks. Other facilities would typically include haul roads, railroad spurs, conveyors, coal handling and loading facilities, storage facilities, and offices.

K. Proximity to Transportation: Main lines of the Burlington Northern Railroad ring the northern Powder River basin on the north, west, and south, and several existing and planned spurs of these lines extend into the center of the area. All existing and currently proposed mines are within a few miles of these spurs. Additionally, the area is served by a network of federal and state highways.

L. Common Transportation Mode: Trucks and conveyor belts to nearby facilities for load out to unit trains on which the coal is shipped.

M. Community Infrastructure Requirements: There are several established communities with trained manpower in the region. Electric power can be derived from coal-fired power plants within and around the region.

II. GENERAL MINING CONDITIONS

A. Structural Attitudes: Coal beds generally dip toward the center of the basin at angles of 1° or less. Locally, steeper dips may reach several degrees. Known faults in the region are generally widespread except in a few areas where they are particularly common and the geologic structure is correspondingly complicated.

B. Topographic Relief: The terrain in the northern Powder River basin is a highly-dissected plateau. Most of the landscape is in moderate to steep slopes; a few upland areas are relatively broad and flat, and the valley bottom are narrow. Local relief is typically 200 to 500 ft.

C. Maximum Overburden: All of the major coal beds crop out some place in the region, and many of them extend underground to areas where the overburden is so thick as to prohibit surface mining. There are extensive areas where the overburden is 200 ft thick or less, although these areas are commonly expressed as only narrow bands along valleys. The overburden is greater under broader areas beneath the undissected uplands; however, the thickness of some of the seams in this area may make removal of large amounts of overburden economically feasible.

D. Market: The steam coal market offers the greatest demand for coal from this area, which is used for this purpose locally and throughout the northern Midwest. In the future, coal from this area will probably also supply coal conversion plants as they are developed within and around the area.

III. TYPICAL COAL BED CHARACTERISTICS

A. Analysis, As-Received: 6,500 to 9,850 Btu/lb; 0.11% to 1.63% sulfur; 3.8% to 10.6% ash; 13% to 42% moisture; 21% to 40% volatile matter; and 22% to 47% fixed carbon.

B. Thickness of Coal: More than a dozen beds 4- to 10-ft thick; several beds are 10- to 30-ft thick; and at least three beds are 30- to 80-ft thick.

C. Mining Problems: Major problems with burned coal, and, locally, with faulting; some problems with water in mines, but often mine water can be used on site.

FORT UNION COAL REGION

WILLISTON BASIN AREA

The Williston basin of the Fort Union coal region has not been as intensely explored for coal recently as has been the northern Powder River basin. Nevertheless, the Williston basin is deserving of particular attention because it contains approximately 10 billion tons of strippable lignite, which amounts to over 60% of the strippable lignite in Montana and roughly 20% of the strippable reserves of all types of coal in the state. One surface mine in the Williston basin produced over 300,000 tons of coal in 1978. In the Williston basin there are at least eight minable beds ranging in known maximum thickness from 9 to 54 ft.

I. REPRESENTATIVE MINING OPERATIONS

Presently, only surface mining is being conducted in this area. The great extent of strippable reserves in thick beds precludes major development of underground mines; therefore, only surface mining operations will be considered.

A. Coal Rank: Lignite, typically 6,000 to 7,500 Btu/lb, as-received.

B. Minimum Leasehold Required: Varies because of the wide variation in the thickness of coal beds. The minimum leasehold required for the mining of the thickest beds may be as little as several hundred acres, but for the thinner beds the requirements may be 1,000 to 2,000 acres.

C. Minimum Recoverable Reserves Required: 20 to 30 million tons, assuming a basin-wide recovery factor of 85%.

D. Mine Life: 20 to 30 yr.

E. Coal Price, FOB Mine: Estimated, $5 to $7/ton, current.

F. Design Capacity: The minimum requirement is probably a few hundred thousand tons per year (tpy), and there is one mine in this area that has been producing at this level. However, as in the northern Powder River basin the trend will probably be toward mines with an annual capacity of 1 million tons or more.

G. Mining Technology: Mining will probably depend upon drag lines, with the supplemental use of shovels for stripping.

H. Capital Requirements: \$15 to \$20 million (±20%) for a 1-million tpy mine.

I. Labor Requirements: 100 or fewer people for mines of about 1 million tpy; possibly 300 or more people for mines of several million tons.

J. Surface Equipment: For mining, standard surface-mining equipment, including draglines, shovels for stripping and loading, scrapers, dozers, front-end loaders, and trucks. Other facilities would typically include haul roads, railroad spurs, coal handling and loading equipment, storage facilities and offices.

K. Proximity to Transportation: Most parts of the Williston basin are within 25 miles of one or more existing railroad lines. The area is served by three interconnected main lines of the Burlington Northern Railroad -- one along the Yellowstone River valley, one along the Missouri River valley, and one that extends eastward from Glendive on the Yellowstone River. Three branch lines extend westward from the Yellowstone River valley, and several other branch lines serve adjacent areas of western North Dakota. Additionally, a main line of the Milwaukee Road extends east-west across the southern part of the basin. There are several state and federal highways in the area that generally follow the railroads.

L. Common Transportation Mode: Trucks and/or conveyor belts to nearby facilities for load out to unit trains on which the coal is shipped.

M. Community Infrastructure Requirements: There are several established communities in the area with at least some trained manpower. Electric power can be derived from existing and proposed coal-fired power plants within and around the region.

II. GENERAL MINING CONDITIONS

A. Structural Attitudes: Beds dip generally a few degrees or less, commonly as little as 1° or less. The direction of dip varies with position relative to regional structural features. Higher dips are found locally in areas of faulting.

B. Topographic Relief: This area is a part of the Missouri Plateau division of the Great Plains physiographic province. The terrain is flat to gently rolling and moderately dissected. Local relief may amount to up to a few hundred feet.

C. Maximum Overburden: Large reserves at most fields in the area lie beneath 150 ft or less of overburden. The thickness of some of the coal beds may determine stripping ratios favorable for removing even thicker overburden.

D. Market: The steam coal market will provide the greatest demand from coal in this region, which could supply power plants in the region and throughout the northern Midwest. This coal is also suitable for gasification.

III. TYPICAL COAL BED CHARACTERISTICS

A. Analysis, As-Received: 6,000 to 7,5000 Btu/lb; 0.3% to 0.9% sulfur; 5.9% to 10.7% ash; and 30% to 40% moisture.

B. Thickness of Coal: Of the eight major beds in the region, only one has a maximum thickness of less than 10 ft, whereas four beds reach thicknesses of 10 to 30 ft, and three beds reach thicknesses between 40 and 54 ft.

C. Mining Problems: Probably some problems with burned coal and water in mines.

OTHER COAL REGIONS

Montana contains coal reserves of varying quality in a variety of areas and geological settings outside of the Fort Union region. However, these areas have been of only secondary interest in recent years, and they have not been as thoroughly explored and described as the Fort Union region (see General Statement and Coal Characteristics). Recent exploration and development by industry has focused on the Great Falls and Red Lodge fields. Both of these fields contain bituminous coal.

The Great Falls field is contiguous with the Lewistown field. The coal in this area is high-volatile B and C bituminous with a typical heating value of 10,200 Btu/lb, as-received. The ash content varies widely, and the sulfur content ranges from 1.7% to 4%. The Belt Creek bed in the Great Falls field has produced coking-coal in the past. A major problem in the field as a whole is that the thickness of coal is inconsistent, although the maximum thickness appears to be about 18 ft.

The Red Lodge field contains eight major coal beds, ranging in thickness from 3.5 to 10 ft, in the Paleocene Fort Union formation. The Red Lodge field is contiguous with the Bridger and Silvertip fields and close to the Stillwater field, but the coal in these fields is in Cretaceous formations, and the minable beds are fewer and thinner. The coal in the Red Lodge field is typically high -volatile C bituminous with a heating value of 10,000 Btu/lb, as-received. The ash content of the coal is typically 13.4%, and the sulfur content ranges from 1.0% to 1.3%. The coal in the Red Lodge field has been underground-mined in the past, and there have been plans to reopen an existing underground mine there.

Another area of potential coal mine development in Montana is the Bull Mountain field, which contains subbituminous coal in 26 persistent coal beds in the Tertiary Fort Union Formation. Some of these beds are strippable, and surface mining operations in this region would probably be very similar to those in the northern Powder River basin.

CONVENTIONAL MINE DEVELOPMENT MODEL

NEW MEXICO

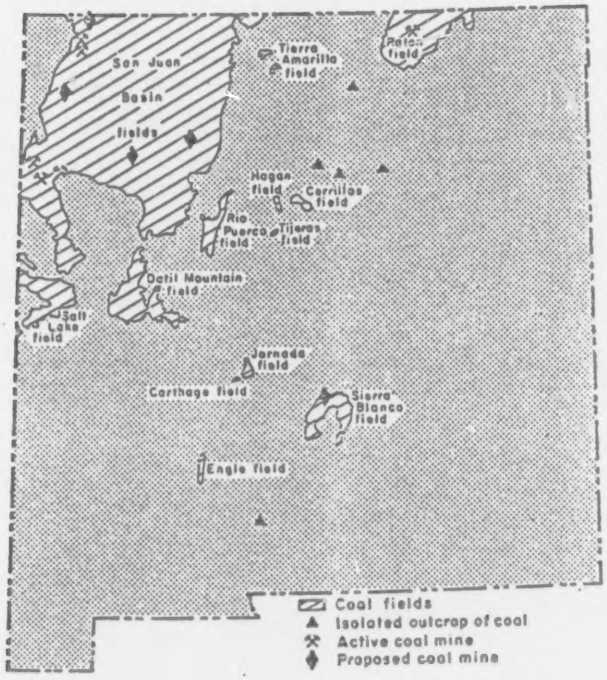
GENERAL STATEMENT

Of the 14 coal-producing states west of the Mississippi River in 1979, New Mexico ranked eighth in production with an output of 10.7 million tons. New Mexico's annual production is planned to increase four-fold, to 42.8 million tons, by 1990. This would rank New Mexico fifth out of the 16 coal-producing states west of the Mississippi River in that year. New Mexico's rate of growth would be the greatest of any of the 14 states that produced in 1979. By 1990 production will be comparable to that from Utah and Colorado, and will greatly exceed that from Arizona, which it now trails slightly.

Over 95% of the estimated remaining coal resources of New Mexico occur in the San Juan basin in the northwest corner of the State. This basin has been divided into 19 smaller coal fields and areas. The rest of the estimated coal resources of the State occur in 10 other coal fields and areas. More than half of thse resources are in the Raton field in the north-central part of the State. The other nine coal areas occur in the western and central parts of the State.

Mining Method: In the San Juan basin, in 1979, there were four surface mines and no underground mines. Current proposals indicate that by 1990 there could be 15 surface mines and two underground mines in the San Juan basin. In the Raton field there was one surface mine and one underground mine in 1979. No new mines are now planned for this area. There are now no major operating or proposed mines in other areas of the State.

New Mexico


San Juan Basin fields
Tierra Amarilla field
Raton field
Hagan field
Cerrillos field
Rio Puerco field
Tijeras field
Datil Mountain field
Salt Lake field
Jornada field
Carthage field
Sierra Blanca field
Engle field
▨ Coal fields
▲ Isolated outcrop of coal
⚒ Active coal mine
♦ Proposed coal mine

Coal Fields in New Mexico

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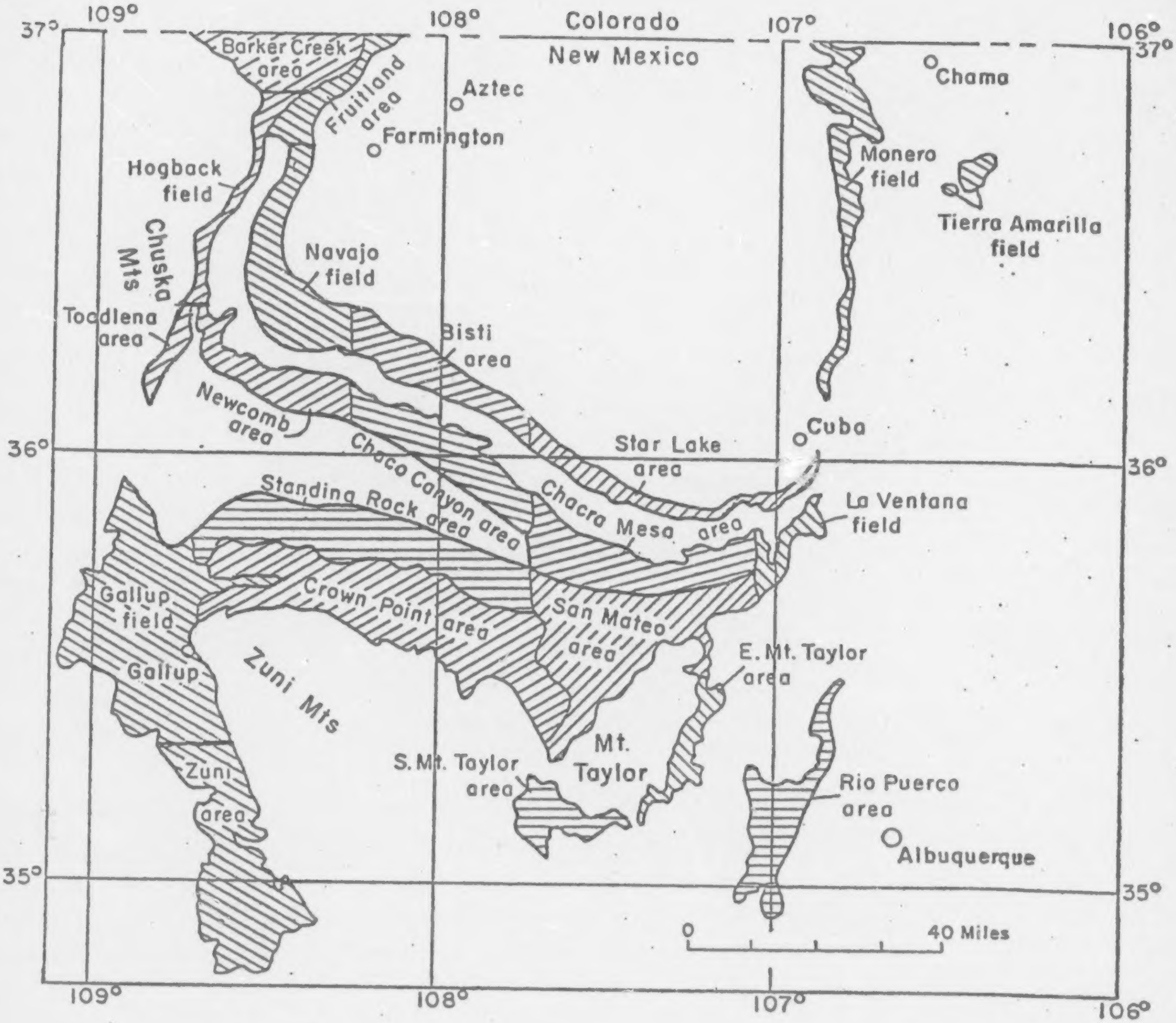
37°
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Colorado
New Mexico
107°
106°
37°
Barker Creek area
Fruitland area
Aztec
Farmington
Chama
Hogback field
Chuska Mts
Navajo field
Monero field
Tierra Amarilla field
Toadlena area
Bisti area
Newcomb area
Chaco Canyon area
Star Lake area
Cuba
36°
36°
Standing Rock area
Chacra Mesa area
La Ventana field
Gallup field
Crown Point area
San Mateo area
Gallup
Zuni Mts
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Mt. Taylor
S. Mt. Taylor area
Zuni area
Rio Puerco area
Albuquerque
35°
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40 Miles
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Coal Fields in the San Juan Basin.

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Mine Size: In 1979 the only underground mine in New Mexico produced 0.8 million tons of coal. That year, production from surface mines ranged from 0.1 to 4.0 million tons. By 1990 the design capacity of the largest underground mine will be 1.5 million tons per year (tpy). At that time the design capacities of surface mines will range from 0.3 to 5.5 million tpy, with the design capacities of 9 of the 16 surface mines in the State ranging from 2.0 to 3.9 million tpy (Table 1).

Utilization: Coal currently produced from the San Juan basin is used for steam-generation of electricity in New Mexico, Arizona, and California. In the future, some coal will also be shipped to Texas for this purpose. Coking coal, mined in the Raton field, has been used mostly in Kaiser Steel Corporation's mill in Fontana, California, although some has been shipped to other users in Colorado and in Monterrey, Mexico.

Future Potential: Future demand for steam coal for the areas now supplied from the San Juan basin should increase. Kaiser Steel Corporation, the only current and proposed producer of coal from the Raton field, does not now plan to increase its production of coking coal.

COAL CHARACTERISTICS

Rank: The main coal resources of New Mexico, in late Cretaceous and early Tertiary formations, are generally subbituminous A to high-volatile bituminous in rank. The full range of rank of these coals, however, is from subbituminous B to anthracite. In the San Juan basin the coals of the Upper Cretaceous Mesaverde Group range upward in the section from nonagglomerating subbituminous A and B to high-volatile C and B bituminous. In this area the coals in the higher, Upper Cretaceous Fruitland Formation, range in rank from nonagglomerating subbituminous A to high-volatile, nonagglomerating subbituminous C. The rank of these coals generally increases northward. In the Raton field there are coking coals of A and B bituminous rank. Coking coals of similar rank are found in the

TABLE 1

Projected Design Capacities for Annual Production from Coal Mines in New Mexico

(including only mines that will be producing in 1990)

Area	Type of Mine	Number of Mines	Design Capacity (millions of tons per year)					
			<1	1.0-1.9	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9
San Juan Basin	Surface	15	2	2	5	4	1	1
	Underground	2	0	2	0	0	0	0
Raton Field	Surface	1	1	0	0	0	0	0
	Underground	1	1	0	0	0	0	0

Carthage and Cerrillos fields. The Cerrillos field also contains some anthracite and semianthracite.

The rank of coals in New Mexico appears to depend more on the effects of nearby igneous activity and structural deformation than depth of burial. For example, the coals in the Raton field are some of the youngest in New Mexico and were probably never buried very deeply, but some of these coals are among the highest ranking in the State.

Sulfur Content: The sulfur content of most coals in New Mexico ranges from 0.4% to 1.0%, although coals in the Menefee Formation of the Mesaverde Group in the Monero field of the San Juan basin have sulfur contents that range up to 3.5%. Most coals from the San Juan basin contain about 0.5% organic sulfur, and up to this amount of sulfur may occur as sulfate and pyritic sulfur in coals having up to 1.0% total sulfur.

Heating Values: In northwestern and central New Mexico, the coals from the Mesaverde Group and Formation range in heating value from 9,800 Btu/lb to 15,200 Btu/lb, with an average of about 13,000 Btu/lb, on a dry, ash-free basis. In northwestern New Mexico, on a similar basis, coals in the Fruitland Formation range from 9,100 Btu/lb to 14,100 Btu/lb, with an average of 12,100 Btu/lb. In the Raton field, coals in the Raton Formation range from 12,700 Btu/lb to 14,340 Btu/lb, and coals in the Vermejo Formation range from 10,030 Btu/lb to 13,220 Btu/lb, both on a dry, ash-free basis. Similar analyses of the anthracites of the Cerrillos field show a range of 14,600 Btu/lb to 15,100 Btu/lb.

Moisture Content: Coals from the Mesaverde Group and Formation range in moisture content from 1.7% to 21.3%, with an average of about 15%. Coals from the Fruitland Formation range in moisture content from 4.5% to 15.6%, with an average of about 14%. Coals in the Vermejo and Raton Formations range from 1.9% to 11.2%, with an average of about 6%.

Volatile Matter: Volatile matter has not generally been analyzed in coals from New Mexico. Average analyses for a few areas from the San Juan basin show volatile matter contents of 24.9% to 38.5%. From the Raton field an average analysis of the York Canyon seam, which is currently being mined, has a volatile matter content of 35.7%.

Ash Content: The ash contents of coals from the Raton field average about 14%. The ash contents of coals from the Mesaverde Group in the San Juan basin range from 3.1% to 22.8% and average about 11%. Coals mined from the Mesaverde Formation outside of the San Juan basin have ash contents that range from 4.5% to 16.9%, with an average of about 11%. Coals mined from the Fruitland Formation have ash contents that range from 10.1% to 21.6%.

COAL CONVERSION

The moderate to high rank of much of the coal of New Mexico means that it is not suitable for low-Btu gasification. However, many of the high-volatile bituminous coals of this State may be well suited to both the methanation process for high-Btu gas and for liquefaction. Currently, one high-Btu gasification plant is planned for San Juan County in the San Juan basin.

RATON FIELD

The Raton field is the largest coal-bearing area in New Mexico outside of the San Juan basin. The Raton field contains 4,709 million tons of undifferentiated strippable and deep coal resources. This is only 2.6% of the total coal resources of the State, but it is 60% of the currently estimated remaining coal resources outside of the San Juan basin.

Currently, there are only two mines working in the Raton field, one surface mine and one underground mine, both operated by the Kaiser Steel Corporation. In 1979 the surface mine produced 0.7 million tons and the underground mine produced 0.8 million tons, and it planned that these mines will produce at this rate through the coming decade. No new mines are now planned for this field. In 1979 production from the two existing mines amounted to 14% of New Mexico's total coal production, but by 1990, because of growth elsewhere, production from the Raton field will decline to only about 3.5% of the total for the State.

At this time it is difficult to define representative mining operations for the Raton field. It is difficult to draw general conclusions from the only two existing mines in the area, from which few data are available; and the lack of proposed mines in the area makes the prediction of future trends highly speculative. Over much of the area the coal is beneath thick overburden, but there are nevertheless considerable strippable reserves. Both underground and surface mining will be addressed, so far as possible or appropriate, under Representative Mining Operations.

I. REPRESENTATIVE MINING OPERATIONS

A. Coal Rank: Mostly high-volatile A to B bituminous coking coal.

B. Minimum Leasehold Requirement: Assuming a minable reserve base of about 20 million tons and an average thickness of 10 ft, which is about the average for the York Canyon seam, the only seam which is now mined, a surface mine would require about 1,000 acres. An underground mine, because of the much lower recovery factor, would require roughly twice as much acerage. Data on the thickness of other seams in the area are lacking, but it appears that the other seams are generally thinner than the York Canyon seam. Thus, only by mining multiple seams could the required leasehold for a given reserve base be reduced in area.

C. Minimum Recoverable Reserves Requirement: For mines of the annual capacity of the existing mines, possibly 20 million tons, more or less. Few smaller mines are expected to be operating in the State in the next decade.

D. Mine Life: 20 to 30 years.

E. Coal Price, FOB Mine: Estimated $20 to $30 per ton (much of it in a captive market).

F. Design Capacity: The two existing mines in the Raton field have design capacities of less than 1 million tons, although most mines in the State, including underground mines, have larger capacities.

G. Mining Technology: Probably standard mining technology can be used for both surface and underground mines. Retreating longwall mining equipment is employed in the York Canyon underground mine.

H. Capital Requirements: For a surface mine of about 1 million tons per year (tpy) capacity, the capital requirements are $15 to $20 million (±20%). For an underground mine of similar annual capacity, the capital requirements are $35 to $40 million (±20%).

I. Labor Requirements: Typical requirements for surface mines in other areas fall in the range of 50 to 100 employees per million tons of coal produced annually. Requirements for underground mines may be up to several times higher.

J. Surface Equipment: For surface mines, standard mining equipment such as draglines, shovels, dozers, front-end loaders, trucks, and so on may be used. Support facilities might include railroad lines, haul roads, conveyors, coal storage and loading facilities, coal washing and thermal drying facilities, and offices. An underground mine might require similar support facilities.

K. Proximity to Transportation: This area is served by a main line of the Atchison, Topeka, and Santa Fe Railroad, and by a branch of this railroad that serves the existing mines. The region is also convenient to several Federal and State highways.

L. Common Transportation Mode: Coal would probably be locally transported by conveyor and truck to railroad facilities for shipment on unit trains.

M. Community Infrastructure Requirements: There are a few small towns in the area, notably York and Raton, New Mexico, that might provide a community basis for expansion of coal mining. At this time there is probably neither a deficit nor an excess of trained manpower in the area.

II. GENERAL MINING CONDITIONS

A. Structural Attitudes: The Raton field lies within a shallow, arcuate syncline, the Raton basin. Overall, the structural geology of the field is comparatively uncomplicated. In the eastern and central parts of the field the beds are nearly flat-lying or are gently dipping. There are few faults.

B. Topographic Relief: The Raton field lies in rugged, dissected plateau at the western edge of the Great Plains. The plateau is cut by many west- to northwest-trending canyons. These provide direct access to the coal seams, which are exposed along canyon walls; and in the past, underground mines have taken advantage of this circumstance.

C. Maximum Overburden: There are no data available on overburden in the Raton field, but most of the resources of the area are considered too deep to surface mine.

D. Market: Currently most of the coal produced from the Raton field is used by the mine owner, the Kaiser Steel Corporation, in its mill in California. In addition, Kaiser sells some of its coal to steel companies with mills in Colorado and Mexico.

III. TYPICAL COAL BED CHARACTERISTICS

A. Analyses: An average analysis for coal from the York Canyon seam, on a moisture-free basis, shows 35.7% volatile matter, 54.9% fixed carbon, 8.8% ash, 0.6% sulfur, and a heating value of 14,340 Btu/lb. Overall in the Raton field, the coals average about 6% moisture, 14% ash, and less than 1% sulfur, as-received.

B. Thickness of Coal: Data are generally unavailable on the thickness of coal in this area, but the York Canyon seam, which is now being mined, is 6 ft to 13 ft thick.

C. Mining Problems: No serious mining problems are anticipated, based on limited data available.

SAN JUAN BASIN

The San Juan basin has been subdivided into 19 coal fields and areas, but there are too few data available on these individually to warrant their separate discussion here.

The San Juan basin contains almost 96% of the presently estimated remaining coal resources of New Mexico, including most of the presently delineated strippable resources. The major coal-bearing units are the Fruitland Formation and the Menefee Formation of the Mesaverde Group, both Late Cretaceous in age. The Fruitland Formation contains an estimated 159,218 million tons of coal resources, of which about 5,041 million tons are considered strippable. The Menefee Formation contains an estimated 12,869 million tons of coal resources, of which an estimated 869 million tons are strippable. These resources are considered strippable if they lie beneath 250 ft or less of overburden. The strippable resources comprise about 3.5% of the total resources of the basin.

Production from the San Juan basin amounted to about 86% of the total for New Mexico in 1979, and by 1990 production from this region should account for over 96% of the total for the State. This is the only coal-producing area of the State in which new or expanded mines are currently planned.

Because the dominant mode of mining in New Mexico, at least over the next decade, will be surface mining, both in terms of numbers of mines and production, only surface mines will be discussed in detail under Representative Mining Operations. Only surface mines are referred to below unless otherwise specified.

I. REPRESENTATIVE MINING OPERATIONS

A. Coal Rank: The coals of the Mesaverde Group range from subbituminous B to high-volatile B bituminous in rank, while the coals of the Fruitland Formation range from subbituminous A to high-volatile C bituminous in rank.

B. Minimum Leasehold Requirements: For a 20-million-ton reserve base, in beds averaging 7 ft thick, a leasehold of about 1,500 acres is required. Most minable beds in the San Juan basin are between 3 ft and 12 ft thick, so leasehold requirements for 20 million tons of reserves will generally range between about 1,000 to 2,000 acres. A few beds are up to about 20 ft thick. If such beds were persistent, their mining might require leaseholds of only several hundred acres. However, coal beds in the San Juan region are typically lenticular and discontinuous. Consequently, the thickest coals may not persist over areas sufficient to significantly reduce leasehold requirements.

C. Minimum Recoverable Reserves Required: The typical surface mine currently planned for the region will probably require 20 to 30 million tons of recoverable reserves, although many mines in this area are probably based on reserves two to four times as large. The minimum required for surface mining also appears to be roughly typical of reserves for underground mines in this region.

D. Mine Life: 20 to 30 years.

E. Coal Price, FOB Mine: The estimated current price of coals from New Mexico range from $12 to $30 per ton.

F. Design Capacity: The average design capacity of currently planned and producing mines is about 2.5 million tons per year (tpy). Most of these mines have design capacities of 2.0 to 3.9 million tpy (Table 1).

G. Mining Technology: Data are unavailable on the technology currently used in surface mining in this area, but it is probable that standard surface-mining technology will typically be used here.

H. Capital Requirements: $15 to $20 million (±20%) are required for a surface mine of 1 million tpy capacity. $35 to $40 million are required for an underground mine of similar capacity.

I. Labor Requirements: Typical requirements for surface mines will probable fall in the range of 50 to 100 employees per million tons of coal produced annually. Requirements for underground mines will probably be several times higher.

J. Surface Equipment: Surface mines in the San Juan basin will require standard surface-mining equipment, such as bucketwheel excavators, draglines, shovels, dozers, front-end loaders, trucks, and so on, as well as support facilities such as haul roads and railroad spurs, coal storage and loading facilities, offices, and conveyors. Underground mines may require many of the same support facilities.

K. Proximity to Transportation: A main line of the Atchison, Topeka, and Santa Fe Railroad passes around the southern part of the San Juan basin and crosses some of its southern fields. A planned spur of this line would extend northeastward to the Star Lake area from the main line east of Gallup, New Mexico. A proposed isolated railroad line in the northwest part of the basin would connect the proposed Burnham mine to the gasification plant which it is to supply. Otherwise, most of the northern basin will be at least 30 miles from current or proposed rail service. The region is also served by several State and Federal highways.

L. Common Transportation Mode: The coal is commonly transported by conveyors and trucks to railroad facilities for shipment on unit trains or to nearby power plants such as the Four Corners power plant near Fruitland, New Mexico.

M. Community Infrastructure Requirements: There are several small towns and the city of Albuquerque in the vicinity of the San Juan basin. These may be able to supply some trained manpower for development of coal resources, however, it is likely that recent expansion of coal mining has already reduced the supply of available, trained labor. Electric power plants in the region should be able to readily supply electricity for mine development.

II. GENERAL MINING CONDITIONS

A. Structural Attitudes: The San Juan basin is structurally one of the simplest coal-bearing areas in New Mexico. The San Juan basin is asymmetric and is deepest in the northeast, where the lowest Cretaceous coal beds are at a depth of approximately 9,000 ft. The Cretaceous and early Tertiary strata on the north and east sides of the basin dip steeply; but these beds have gentle dips, mostly from 2° to 6°, in the southern and western parts of the basin. There are only a few minor faults in the basin.

B. Topographic Relief: The San Juan basin is part of the Colorado Plateau physiographic province. It consists of rolling topography of moderate relief and is dissected by the San Juan River and its tributaries.

C. Maximum Overburden: Overburden on the main Cretaceous coal beds ranges up to 9,000 ft. Strippable deposits in this area are considered to lie beneath 250 ft of overburden. Such deposits contain 5,910 million tons of coal resources, which are about 3.4% of the total coal resources of the basin.

D. Market: The steam coal market provides the greatest demand for coal from the San Juan basin, which is shipped to electric power plants in New Mexico, Arizona, and California. Texas is a probable future market for this coal. Some coal from this basin is planned to supply a proposed nearby gasification plant.

III. TYPICAL COAL BED CHARACTERISTICS

A. Analyses, As-Received: Representative average or mean analyses are available from only some of the fields in the San Juan basin. The range and mean of these representative values are as follows:

1. Moisture: The reported representative moisture contents from seven fields range from 4.4% to 14.9%, with an average of 10.3%.

2. Volatile matter: The reported representative volatile matter contents from three fields range from 24.9% to 38.5%, with an average of 33.1%.

3. Fixed carbon: The reported representative fixed carbon contents from three fields range from 38.1% to 41.5%, with an average of 39.8%.

4. Ash: The reported representative ash contents from nine fields range from 5.2% to 24.0%, with an average of 13.8%.

5. Sulfur: The reported representative sulfur contents from nine fields range from 0.50% to 21.0%, with an average of 0.84%.

6. Btu/lb: The reported representative heating values, in Btu/lb, for nine fields, ranges from 8,900 to 12,945, with an average of 10,492.

B. Thickness of Coal: Most of the beds that are considered minable range in thickness from 3 ft to 12 ft. A few beds achieve thicknesses of up to about 20 ft, and the thickest bed reported from the Fruitland field reaches a thickness of 50 ft.

C. Mining Problems: Probably minor, although specific information is lacking.

CRITERIA FOR CHARACTERIZING COAL MINES IN THE WESTERN UNITED STATES

CONVENTIONAL MINE DEVELOPMENT MODEL

NORTH DAKOTA

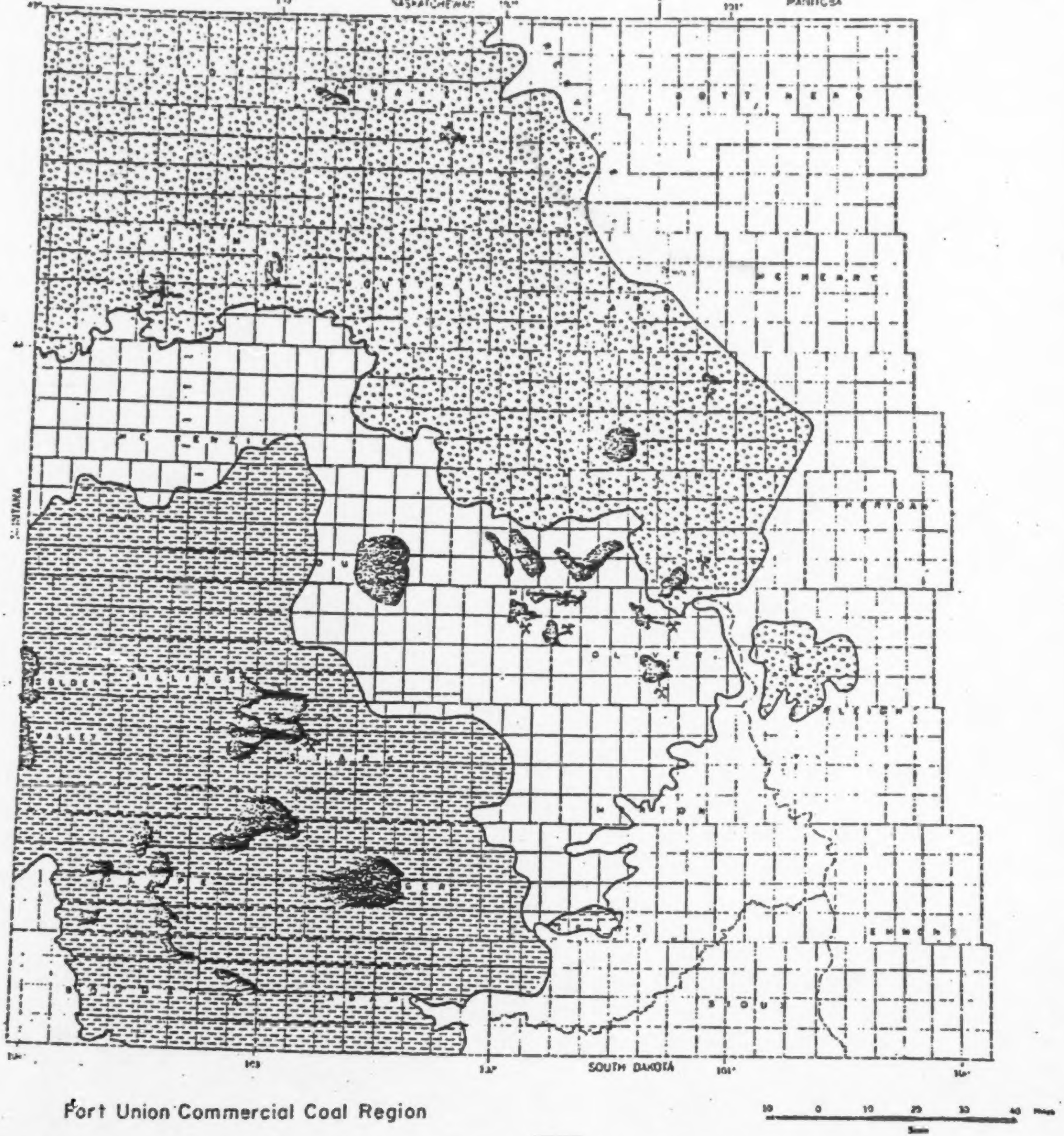
GENERAL STATEMENT

An estimated 351,000 million tons of lignite underlie 28,000 square miles in western North Dakota. This amounts to about two-thirds of the total lignite resources of the United States. The total strippable reserves appear to be only about 16,000 million tons, however, which is somewhat more than half of the strippable lignite reserves in the western United States. The lignite reserves of North Dakota are being actively developed. There are at least nine major, active surface lignite mines scattered throughout the region, with an equal number of new mines proposed. Many of the existing mines plan to expand production. There are also four coal-fired electric power plants in the region, with several more coal-fired electric plants and coal conversion plants proposed or under construction in the area.

Mining Method: All existing and proposed lignite mines in North Dakota are surface mines. The abundance of strippable reserves and the low rank of the lignite make underground mining an unlikely possibility in the forseeable future.

Mine Size: The trend for new and expanding mines is toward production in the range of 1 to 6 million tons per year (tpy). Mines proposed to supply coal conversion plants are generally planned to produce 12 to 14 million tpy per plant. The largest proposed mine, the Amax Mine in Dunn County, would produce 52 million tpy for four coal conversion plants, if they are constructed.

North Dakota


SASKATCHEWAN
MANITOBA
MONTANA
SOUTH DAKOTA
MC HENRY
SHERIDAN
MC KENZIE
GOLDEN
BILLINGS
VALLEY
STARK
OLIVER
MORTON
EMMONS
SIOUX
10 0 10 20 30 40 Miles

Fort Union Commercial Coal Region

▨	Overburden generally includes glacial drift.	☐	Lignite beds thin or absent
☐	Overburden may include thin glacial drift	●	Areas where >5 million tons of strippable reserves have been outlined
▤	Overburden all bedrock	x	Major active mines

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Utilization: The major use of the lignite from North Dakota is for the steam generation of electric power. In the future, a substantial amount may be used by coal conversion plants.

Future Potential: The demand for lignite from North Dakota comes from that state itself and nearby areas of the northern Midwest. This demand should increase. Local demand will increased markedly, however, as new power plants and coal conversion plants are built in and around the lignite-producing region.

COAL CHARACTERISTICS

Rank: Lignite.

Sulfur Content: 0.2% to 1.4%, with average of about 0.6%.

Heating Values: 5,960 to 7,487 Btu/lb, with an average of about 6,780 Btu/lb, as-received.

Moisture Content: 33.5% to 43.8%, with an average of 37.9%.

Volatile Matter: 24.1% to 30.2%, with an average of 26.7%.

Ash Content: 4.4% to 8.0%, with an average of 6.2%.

COAL CONVERSION

Gasification: The lignite resources of North Dakota are particularly suitable for gasification, and at least five gasification plants are proposed in this area, although most of these are still far from construction.

Liquefaction: Lignite is not particularly well suited for liquefaction, and it is unlikely that a liquefaction plant will be developed in this area.

FORT UNION COAL REGION

WILLISTON BASIN AREA

All of the lignite in North Dakota is found in the Tertiary Fort Union Formation in the Williston basin. Over 100 beds that are 4-ft or more thick have been named in this area, but the lack of regional stratigraphic control makes correlation of these beds uncertain. Commercially minable beds occur throughout the region, and most of the commerical production has been derived from six widespread districts. The overall geology of coal in North Dakota is fairly uniform, especially when compared to Montana, where major coal deposits occur in beds of six different geological ages. One variable, however, is the composition of overburden, which is bedrock of the Fort Union Formation in the south, but which includes glacial deposits above the bedrock in the north. This is important for reclamation because the glacial deposits are generally more suitable for use in reclamation than is the bedrock.

I. REPRESENTATIVE MINING OPERATIONS

Because of the low rank of lignite and the abundance of strippable reserves, only surface mines should be considered.

A. Coal Rank: Lignite.

B. Minimum Leasehold Required: The thickness of lignite beds varies by a factor of about 10, roughly from 4 to 40 ft, and the minimum leasehold requirements vary accordingly. Generally, they may be as little as a few hundred acres for the thickest beds and up to about 3,000 acres for the thinnest beds. These estimates assume a total recoverable reserve base of about 20 million tons of coal per leasehold.

C. Minimum Recoverable Reserves Required: 20 to 30 million tons. The fieldwide recovery factor may be 85% or higher.

D. Mine Life: 20 to 30 yr.

E. Coal Price, FOB Mine: Estimated $5 to $7 per ton, current.

F. Design Capacity: Probably at least 1 million tons per year (tpy). In theory, smaller operations may be economically feasible, but the strong trend is towards mines with production capacities of more than 1 million tpy.

G. Mining Technology: Most current operations depend on draglines.

H. Capital Requirements: $15 to $20 million (±20%) for a mine productіng 1 million tpy.

I. Labor Requirements: Fewer than 100 people for a mine producing 1-million tpy or less, and up to 200 to 300 employees for mines producing several million tpy.

J. Surface Equipment: Standard surface-mining equipment, including draglines, shovels, scrapers, dozers, front-end loaders, and trucks. Other facilities would typically include haul roads, railroad spurs, conveyors, coal handling and loading equipment, storage facilities, and offices.

K. Proximity to Transportation: The region is served by two main lines and several branch lines of the Burlington Northern Railraod, as well as by main and branch lines of the Milwaukee Road. Most of the region is within 25 miles of existing rail lines.

L. Common Transportation Mode: Trucks and conveyor belts to nearby facilities for load out to unit trains on which the coal is shipped.

M. Community Infrastructure Requirements: There are several established communities with trained personnel in the region, however, these communities are already supplying manpower to existing mines. The numerous existing and planned power plants in this area will make electricity readily available for mine development.

II. GENERAL MINING CONDITIONS

A. Structural Attitudes: The coal beds are generally flat-lying or very gently dipping. Structural complications have not been reported, but comparison with similar areas in Montana suggests that steeper dips may occur in areas of faults.

B. Topographic Relief: The terrain is generally flat to gently rolling plateau of low relief.

C. Maximum Overburden: The estimated 16,000 million tons of strippable reserves generally lie beneath less than about 100 ft of overburden. Much more lignite lies in deeper beds, and thick beds or combinations of beds may determine favorable stripping ratios for mining in areas of thicker overburden.

D. Market: The coal produced in North Dakota is consumed primarily in North Dakota, northeastern South Dakota, and western Minnesota. The size of the market is limited by the occurrence of comparable and higher ranking reserves immediately to the south and west and by the ease with which higher ranking coal can be shipped from various other areas to the rest of the upper Midwest.

III. TYPICAL COAL BED CHARACTERISTICS

A. Analysis, As-Received: see Coal Characteristics.

B. Thickness of Coal: 2.5 ft to 37 ft or more. In the major mining districts the major beds are typically 7 to 22 ft thick. In some areas multiple beds may be minable and increase the effective thickness of reserves.

C. Mining Problems: Information on this topic is not generally available. Problems should be similar to those in the Fort Union Coal region in eastern Montana, except that burned coal should be less common in North Dakota because the landscape is less dissected and the coal is less exposed.

CRITERIA FOR CHARACTERIZING COAL MINES IN THE WESTERN UNITED STATES

CONVENTIONAL MINE DEVELOPMENT MODEL

OKLAHOMA

GENERAL STATEMENT

The coal resources and production of Oklahoma are modest in comparison with the other Western States considered in these reports. Estimated reamaining coal resources in Oklahoma, in beds not less than 10 in. thick at all depths, are 7,200 million tons. About 9% of these, 680 million tons, are considered strippable. Strippable deposits include coal in beds at least 12 in. thick beneath less than 100 ft of overburden. In 1978 Oklahoma's coal production ranked 20th in the nation, and the State's 1979 output of 3.6 million tons ranked 11th out of 14 producing states west of the Mississippi River. By 1990 Oklahoma's coal production capacity is expected to grow to only 4.0 million tons per year (tpy). This is the slowest rate of growth of any Western State except Arizona, and by 1990 Oklahoma should rank only 13th out of 16 producing Western States.

Oklahoma is unlike the other states considered in these reports in that its major coal beds are in Middle and Late Pennsylvanian rocks in the southern part of the Western Region of the Interior Coal Province. The coal beds are generally thinner and higher in sulfur than the Western coals, and the mines are much smaller than the norm for Western States.

The coal resources of Oklahoma are found in a single, roughly arcuate area of about 8,000 square miles at the northeast corner of the State, although coal-bearing rocks not considered to contain resources extend another 6,500 square miles beyond this. Geologically, the coal-bearing area of Oklahoma can be

Oklahoma

EXPLANATION

MILLIONS OF SHORT TONS

░ 1-50

▨ 51-100

▨ 101-500

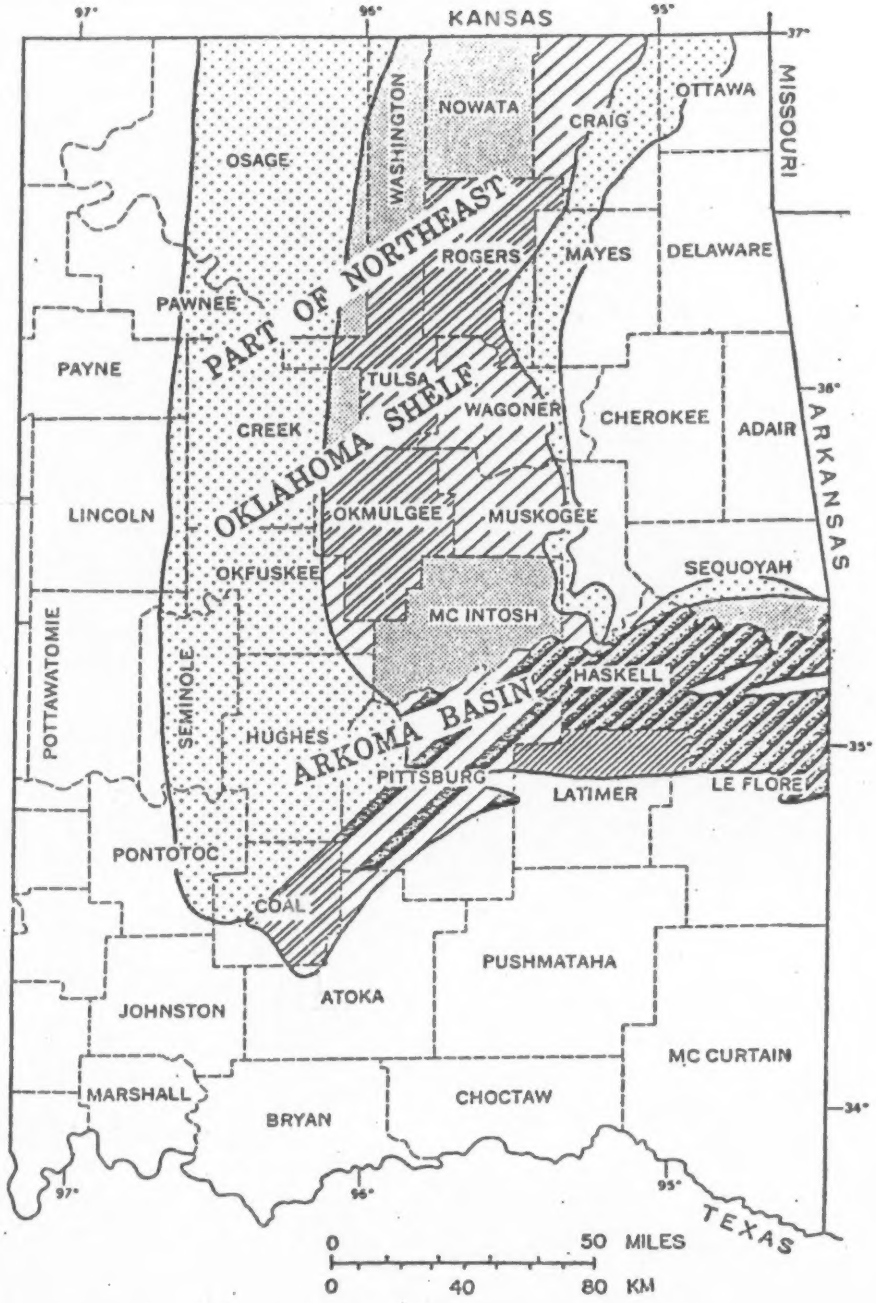
▨ 501-1,000

▨ 1,001-1,500

▨ 1,501-2,000

AREAS KNOWN TO CONTAIN COAL BEDS THAT ARE OF COMMERCIAL VALUE AT THE PRESENT TIME OR THAT MAY BE OF VALUE IN THE FUTURE. MINIMUM COAL BED THICKNESS IS 10 INCHES. (APPLIES TO ALL THE ABOVE PATTERNS.)

░ AREAS OF DOUBTFUL VALUE FOR COAL, CONTAINING THIN BEDS, OR COAL OF POOR QUALITY, OR WHERE INFORMATION ON THE THICKNESS AND QUALITY OF THE COAL BEDS IS MEAGER OR LACKING.


97°
96°
95°
KANSAS
37°
MISSOURI
OSAGE
WASHINGTON
NOWATA
CRAIG
OTTAWA
PART OF NORTHEAST
OKLAHOMA SHELF
ROGERS
MAYES
DELAWARE
PAWNEE
PAYNE
TULSA
WAGONER
CHEROKEE
ADAIR
36°
ARKANSAS
CREEK
LINCOLN
OKMULGEE
MUSKOGEE
OKFUSKEE
SEQUOYAH
MC INTOSH
POTTAWATOMIE
SEMINOLE
HASKELL
ARKOMA BASIN
HUGHES
PITTSBURG
LATIMER
LE FLORE
35°
PONTOTOC
COAL
PUSHMATAHA
JOHNSTON
ATOKA
MC CURTAIN
MARSHALL
BRYAN
CHOCTAW
34°
97°
96°
95°
TEXAS
0
50 MILES
0
40
80 KM

Map showing distribution by county of remaining resources of bituminous coal in Oklahoma

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subdivided into two major regions, the Northeast Oklahoma shelf on the north, which contains about 16% of the State's coal resources, and the Arkoma Basin on the south, which contains about 84% of the State's coal resources. There are some differences between the two geologic areas, but these differences are not so great as those between Oklahoma as a whole and other Western States. Oklahoma is not customarily subdivided into distinctive fields. Coal data are generally compiled by county.

Mining Method: Since 1973 all coal in Oklahoma has been mined by surface methods, with perhaps some incidental exceptions. Between 1872, when commercial mining began in Oklahoma, and 1915, all mining was by underground methods. Between 1915 and 1973, with a few temporary lapses, the proportion of surface mining increased fairly rapidly and steadily. In 1974 it was calculated that the average cost of underground coal mining was about 61% greater than that of surface coal mining, and this was believed to be the main cause of the lack of underground production in recent years. For the coming decade only one substantial producing underground mine is currently planned.

Mine Size: In 1979 the productive capacity of mines in Oklahoma was mostly between 0.1 and 0.4 million tpy, although one mine had a capcity of 0.6 million tpy and one had a capacity of 1.5 million tpy. By 1990 the two smallest existing mines and one new underground mine will expand their capacities to 0.2 million tpy, but the capacities of all of the other mines will remain unchanged (Table 1).

Utilization: In 1976, 82% of Oklahoma's coal production was steam coal for out-of-state electric power plants, and about 18% was coking and other coal for out-of-state coke and manufacturing plants. In recent years the major uses of Oklahoma's coal, in order of decreasing prominence, have been electric power generation, coke manufacture and metallurgical use, and cement manufacture. Of the remaining net recoverable reserves, 1,300 million tons are suitable for coke

TABLE 1

Recent and Projected Design Capacities for Annual Production from Coal Mines in Oklahoma

(all mines are surface mines except as noted)

	Productive Capacity (10^6 tons per year)							
Year	0.1	0.2	0.3	0.4	0.5	0.6	1.5	Total
1979	2	1	1	2	0	1	1	8
1990	0	4[1]	1	2	0	1	1	9

[1] Includes one underground mine.

manufacture, 657 million tons are suitable for electric power generation, including only reserves not suitable for other uses, and 240 million tons are suitable for gasification.

Future Potential: It does not appear that the demand for coal from Oklahoma will grow significantly over the coming decade. Current plans show only about a 10% increase in production over the next 10 years. There will be growth of coal consumption by electric utilities in Oklahoma, but these utilities plan to use coal from Wyoming, which is lower in sulfur than the coal from Oklahoma. Additionally, the cost-per-ton of surface mining coal in Oklahoma is higher than the average in other coal-producing states, although cleaning and reclamation costs are generally lower. The demand for coal from Oklahoma is primarily from nearby areas outside the State.

The greatest potential for long-term future expansion is probably greatest for coal for coke manufacture and gasification. At least one future coke plant, iron smelter, or steel mill within the State could be supported by coal mined there. Coal produced in the State could also support a gasification plant. Coal from Oklahoma could be used to support a large part of the State's own needs for generation of electricity if sulfur were removed from the coal or if statutes were changed to allow the use of higher sulfur coal.

COAL CHARACTERISTICS

Rank: The coals of Oklahoma are bituminous. In the Arkoma Basin they are low- and medium-volatile in the east, high-volatile A and B in the center, and high-volatile C in the west. In the Northeast Oklahoma Shelf, the coals are high-volatile A and B in the south and high-volatile C in the north.

Sulfur Content: Most coals in the Arkoma Basin have average sulfur contents of less than 2.0%, but locally some coals have average sulfur contents of up to 5.0%. Coals of the Northeast Oklahoma Shelf generally average more than

3.0% sulfur, but in some areas the average is only slightly above 2.0%, and in Rogers County the average is only 0.8%.

Heating Values: In the Arkoma Basin the average heating values from 18 sets of analyses of coal from eight beds in four counties range from 11,711 Btu/lb to 14,430 Btu/lb, with an average of 13,629 Btu/lb, on an as-received basis. In the Northeast Oklahoma Shelf, the average heating values from 18 sets of analyses of coal from eight coal beds in seven counties range from 11,562 Btu/lb to 14,117 Btu/lb, with an average of 12,277 Btu/lb, on an as-received basis.

Moisture Content: For the same analyses as described under Heating Values, the average moisture contents of coals from the Arkoma Basin range from 1.0% to 4.7%, with an average of 2.9%; and the average moisture contents of coals from the Northeast Oklahoma Shelf range from 0.9% to 7.1%, with an average of 3.6%.

Volatile Matter: For the same analyses as described under Heating Values the average volatile matter contents of coals from the Arkoma Basin range from 20.2% to 37.2%, with an average of 28.9%; and the average volatile matter contents of coals from the Northeast Oklahoma Shelf range from 29.8% to 45.5%, with an average of 36.6%.

Ash Content: For the same analyses as described under Heating Values the average ash contents of coals from the Arkoma Basin range from 4.2% to 22.6%, with an average of 9.0%; and the average ash contents of coals from the Northeast Oklahoma Shelf range from 4.5% to 19.0%, with an average of 8.2%.

Fixed Carbon: For the same analyses as described under Heating Values, the average fixed carbon contents of coals in the Arkoma Basin range from 48.4% to 72.3%, with an average of 64.9%; and the average fixed carbon contents of coals from the Northeast Oklahoma Shelf range from 44.3% to 61.0%, with an average of 51.7%.

COAL CONVERSION

Gasification: A model gasification process has been used to determine the suitability of Oklahoma's coal reserves for gasification. This model requires high-volatile bituminous coal that ranges in ash from 8% to 10%, with an average of 9%, and that ranges in sulfur from 2.7% to 3.7%, with an average of 3.2%. Oklahoma has about 240 million tons of net recoverable reserves that meet these requirements, of which about 19% can be surface mined. These reserves are adequate to supply a plant that would consume 10 million tons of coal per year for a 20-year period. The State has already determined one principal and three alternative sites for such a plant, based on the availability of coal, transportation, and water. The coal for a gasification plant would require many small mines and would more than double Oklahoma's current and planned production. No gasification plant is now planned, however.

Liquefaction: Liquefaction of coal has not been discussed and is not now planned for Oklahoma.

SOUTHERN PART, WESTERN REGION, INTERIOR COAL PROVINCE

All of the coal in Oklahoma is found in the southern part of the Western region of the Interior Coal province. As noted above, this coal-bearing region consists of two contiguous, integrated geologic areas, the Northeast Oklahoma Shelf and the Arkoma Basin. All generalizations that apply to the State as a whole apply to this single region.

I. REPRESENTATIVE MINING OPERATIONS

A. Coal Rank: See discussion under Rank above.

B. Minimum Leasehold Requirement: For a recoverable reserve base of 200,000 tons, assuming a recovery factor of 80% and an average coal bed thickness of 1.5 ft to 3 ft, the minimum leasehold required would be roughly 50 to 100 acres.

C. Minimum Recoverable Reserves Requirement: 200,000 tons for a mine producing 0.1 million tons per year (tpy) for 20 years.

D. Mine Life: 20 to 30 years.

E. Coal Price, FOB Mine: Recent spot prices for steam coal from Oklahoma ranged from $18/ton for coal with 3.1% to 4.0% sulfur and 12,000 Btu/lb to $28.50/ton for coal with 0% to 0.75% sulfur and 13,000 Btu/lb. Prices for coking and metallurgical-grade coal are not available.

F. Design Capacity: Most of the new or expanded mines currently planned to be in operation over the next decade will have design capacities of 0.2 to 0.4 million tpy. Two mines will be larger, with design capacities of 0.6 and 1.5 million tpy. According to current plans, if a gasification plant that consumed 10 million tpy were to be built, it would probably be supplied by about 20 mines producing an average of about 0.5 million tpy each.

G. Mining Technology: Standard surface-mining technology is now used in Oklahoma.

H. Capital Requirements: In 1969 it was estimated that a surface mine producing 1 million tons of coal annually would cost about $16 million in the Interior province. More recent estimates for this area are unavailable.

I. Labor Requirements: In 1969 it was estimated that a mine producing 1 million tpy of bituminous coal would require 93 employees. No other estimates are available.

J. Surface Equipment: Surface coal mines in Oklahoma will have standard surface mining equipment, such as trucks, drills, dozers and graders, shovels, draglines, and so on, as well as support facilities such as haul roads, railroad spurs, offices, coal loading and storage facilities.

K. Proximity to Transportation: Eastern Oklahoma is served by the main lines of several railroads, including the Missouri-Kansas-Texas Railroad, Missouri Pacific Railroad, Kansas City Southern-Louisiana and Arkansas Railways, and St. Louis and San Francisco Railway. Additionally, this area is served by several state and local highways and the Arkansas River waterway.

L. Common Transportation Mode: In 1976, 191,484 tons of coal were shipped from Oklahoma by barge; the remainder was shipped by railroad and truck.

M. Community Infrastructure: There are numerous small towns in eastern Oklahoma. Because coal has been produced on and off at many localities throughout this region, there is probably a moderate reservoir of trained manpower that is not now being used. However, as little expansion of mining in this area is now planned, the availability of trained labor is not crucial. The community infrastructure in the region could probably support moderate expansion adequately, but would probably be insufficient as-is to support the level of development required to supply a gasification plant.

II. GENERAL MINING CONDITIONS

A. Structural Attitudes: Coal beds in the Northeast Oklahoma Shelf generally dip westward at angles of ½° to 2°. Coal beds in the Arkoma Basin occur in eroded, southwest-plunging folds. Dips of the coal beds in this area range from less than 3° to nearly vertical, and the structure is complicated by faults. In the past, beds with dips of up to 65° were mined, but recent mining has been limited to beds dipping about 5° or less, although some steeper beds are being mined.

B. Topographic Relief: The southern part of the coal-bearing area extends into the Arkansas Valley section of the Interior Highland physiographic province. This area includes two subsections: (1) The Arkansas Hill and Valley belt of broad, gently rolling plains and valleys with scattered hills from 100 ft to 300 ft, and (2) The McAlester Marginal Hills belt with broad hills and mountains 300 ft to 2,000 ft high above wide, hilly plains. The Northeast Oklahoma Shelf area includes the Neosho Lowland and Claremore and Eastern Sandstone Cuesta Plains subsections of the Sandstone Hills section of the Osage Plains of the Central Lowlands. The Neosho Lowlands are gently rolling lowlands with a few escarpments and buttes. The Cuesta Plains comprise broad plains divided by gently westward-dipping cuestas of differing lithologies.

C. Maximum Overburden: The lowest major coal bed in Oklahoma occurs at the base of a 5,500-ft-thick stratigraphic section. Strippable coal deposits are generally considered to have less than 100 ft of overburden. However, in some cases of particularly thick beds or groups of beds, coal has been surface mined to depths of 120 ft to 140 ft. Underground mining has reached depths of 1,600 ft, and deeper mines have been contemplated.

D. Market: Presently, the markets for all of Oklahoma's coal lie outside of the State. In 1976, about 18% of the State's production was for coking and manufacturing uses. Much of this coal was shipped to Texas and Japan. The remainder of the State's production that year was steam coal, most of which was shipped to areas in the Midwest.

III. TYPICAL COAL BED CHARACTERISTICS

A. Analyses, As-Received: See Coal Characteristics above under the General Statement.

B. Thickness of Coal: In the Northeast Oklahoma Shelf, the coal beds are 0.8 ft to 5.0 ft thick. In the Arkoma Basin, the coal beds are 1 ft to 7 ft thick.

C. Mining Problems: Steeply dipping beds can be a problem for all types of mines. Methane gas is a serious problem in some of the deeper underground mines in Oklahoma.

CRITERIA FOR CHARACTERIZING COAL MINES IN THE WESTERN UNITED STATES

CONVENTIONAL MINE DEVELOPMENT MODEL
UTAH

GENERAL STATEMENT

The principal coal resource of Utah--i.e., coal lying under less than 3,000 ft of overburden and occuring in beds at least 4 ft in thickness--underlies only 4 percent of Utah, or approximately 3,400 sq mi. Most coal mining operations in Utah today are in coal beds at least 8 ft thick; and all present mining operations are underground, with recoverability factors of between 33 and 50 percent. In underground mining in the United States today, optimum recovery is in coal beds between 4 and 12 ft in thickness (coals greater than 12 ft thick cannot be completely mined with equipment being used today in the U.S.).

Mining Method: All underground in Utah at the present time; however, plans have been submitted to the responsible agencies for surface mines in Emery and Kane Counties. Longwall machines show excellent potential in certain fields in Utah amenable to underground mining. However, such equipment is very expensive, affordable only by large coal mines (i.e., those producing more than 700,000 tons/yr). Shortwall mining is an attractive, less expensive option. Presently, most mines use the conventional room and pillar mining method with continuous miners.

MINE SIZE:

The trend in Utah is toward mines producing more than 200,000 tons per year. There are 8 mines producing less than 200,000 tons/year, 5 are parts of larger mining complexes or are in a stage of development, eventually to produce far more coal. Six mines are in the 200,000 - 400,000 ton class and all but one are parts of larger mining complexes (groups of mines controlled by a single mining company). There are 8 mines producing between 400,000 and 800,000 tons/year and constitutes the average successful mining operation in Utah. Three mines produce greater than 800,000 tons per year with two of them producing more than 1.5 million tons.

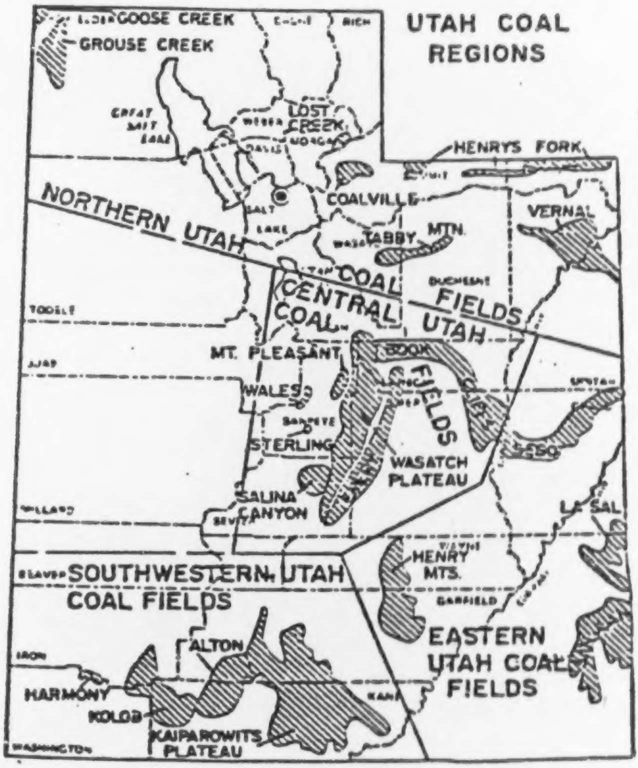
UTILIZATION:

Currently, three-quarters of Utah's coal production is sold for steam electric power generation; about 20 percent is sold into the industrial market of which a little less than half is for metallurgical purposes. The remainder is used for space heating, either being sold in coal yards or distributed to the miners. In 1979, 45 to 50 percent of the coal was destined for Utah markets, the remainder left for Nevada, California, Indiana, Idaho, Mississippi, Washington, Montana, Wyoming, Arizona, Nebraska, Illinois, and Hong Kong.

FUTURE POTENTIAL:

Steam coal, coking coal, coal conversion (gasification and liquefaction); at the present time, all thermal electric generating stations in Utah burn coal as their primary fuel. Increasing requirements for coal for new power generation

Utah


UTAH COAL REGIONS
GOOSE CREEK
GROUSE CREEK
RICH
GREAT SALT LAKE
WEBER
LOST CREEK
DAVIS
MORGAN
HENRYS FORK
COALVILLE
SALT LAKE
VERNAL
TABBY MTN.
NORTHERN UTAH COAL FIELDS
DUCHESNE
TOOELE
CENTRAL UTAH COAL FIELDS
BOOK
MT. PLEASANT
JUAB
WALES
UINTAH
SANPETE
STERLING
WASATCH PLATEAU
SEGO
SALINA CANYON
MILLARD
SEVIER
LA SAL
WAYNE
HENRY MTS.
BEAVER
SOUTHWESTERN UTAH COAL FIELDS
GARFIELD
EASTERN UTAH COAL FIELDS
ALTON
IRON
HARMONY
KOLOB
KANE
KAIPAROWITS PLATEAU
WASHINGTON

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facilities in the state will come from the Book Cliffs and Wasatch Plateau coal fields in Carbon and Emery Counties. Additional power generation, for which Utah may supply coal, is scheduled for Nevada and California. A modest increase in industrial coal utilization in Western States will draw principally from Utah and Colorado; those states west or in line with Utah will obtain their coal from lthe Wasatch Plateau or Book Cliffs coal fields. The current (1979) production is 12 million ton/year, which is expected to rise to between 15 and 20 million tons by 1985 and to between 25 and 30 million tons/year by 1990. The large untapped Southwestern Utah coal fields (Kaiparowits Plateau, Alton, Kolob) will probably remain so because current transportation systems cannot be economically constructed to export the coal from the region and clean-air and environmental regulations prohibit its use in the area.

COAL CHARACTERISTICS:

Rank. The majority of Utah's commercial coals are high-volatile A, B, or C bituminous (i.e., steam coal and high Btu industrial coal).

Sulfur Content. 0.4 to more than 6 percent; most being mined today are 0.4 to 0.8 percent sulfur. Most of this sulfur is organic; usually less than 1/2 of the contained sulfur can be removed by washing the coal; the remainder requires stack gas scrubbers.

Heating Values. Coals range from 8,500 to 13,500 Btu/lb.; most being mined today is greater than 12,000 Btu/lb.

Moisture Content. 3.4 to more than 19 percent; average 4-6 percent.

Volatile Matter. 11 to greater than 46 percent; mostly in the 35-45 percent range.

Ash Content. 4 to greater than 28 percent; most mined coals contain less than 11 percent ash.

COAL CONVERSION:

Gasification. Most of Utah's coal is bituminous in rank, hence may not be very amenable to the Lurgi gasification process (at least the low-Btu gas process), which works better using lignite and subbituminous (i.e., non-caking) coals. Utah's caking coals may work better in the methanation process (i.e., for high-Btu gas). The surface-minable subbituminous coals in parts of Utah (e.g., in the Alton field, in Kane Co.) should be suitable for the production of low-Btu gas by the Lurgi process, for example

Liquefaction. Most of the sulfur content of Utah coals should be removed by the hydrogenation phase of the liquefaction process. The resulting liquid hydrocarbon would be low in sulfur content. Utah's high-volatile bituminous coals generally are considered to be superior to both lignite and subbituminous coal for liquefaction; in fact, they may be more satisfactory for liquefaction processes than most other coals in the United States (excluding coals in western Colorado, which are similar in many respects to the better quality bituminous coals in eastern and central Utah). The underground-mined high-volatile bituminous coals of Utah should be as attractive in the economic sense as surface-mined coals both for gasification to high-Btu gas (methanation process) and for liquefaction.

UINTA COAL REGION

Book Cliffs Coal Field:

To date this field has produced approximately 231 million tons of coal, or 60 percent of Utah's total production. Although the field is historically Utah's leading coal producer, since 1973 it has been surpassed by the Wasatch Plateau coal field each year. Coal production from this field in 1979 was utilized as follows: for steam-electric power generation, 41.3%; for metallurgical (coking) purposes, 37.8%; and for industrial use, 20.8%.

Coals in the Book Cliffs field, for the most part, are minable only by underground methods. the beds are of relatively low dip and are little disturbed by faulting or other structural complications. Most of the presently minable coal reserves in the field are fairly close to railroad mainlines or spurs.

I. Representative Mining Operations (due to high costs of opening new underground operations in the field, only mines of 200,000 or more tons/year should be considered in this model).

A. Rank: High-volatile A or B bituminous.

B. Minimum Leasehold Required: 1000 acres including Federal, Private, and state lands. This is based on a 12-foot coal bed. At a 6-foot average coal-bed the land required would be increased to 1800 acres. A greater thickness would result in a decrease in recoverability, hence 1000 acres would be the minimum. (35 years at 200,000 ton/year on 1000 acres having an average thickness of 12 feet and 30 years at 200,000 ton/year on 1800 acres having an average thickness of 6 feet.) The configuration of the lease will also be important, i.e., those with narrow and jagged outlines will require larger minimum acreages to make up for the loss in recoverability.

C. Minimum Recoverable Reserves Required: 6 million tons = 200,000 x 30 yrs.

D. Mine Life: 25 or more years.

E. Coal price, FOB mine: $20-25/ton today and more for coking coal.

F. Design Capacity: Minimum of 200,000 tons; most of the proposed new mines are in the 1+ million tpy range.

G. Mining Technology: Continuous miners (room and pillar mining); with a trend toward longwall equipment in the mines producing 700,000 tons/year or more.

H. Capital Requirements: Approximately $35 to 40 million (±20%) for an underground mine of 1 million tpy capacity (coking coal mines would be at the higher end of this range). In 1973-74, this figure was about $12-13 million, according to U.S. Bureau of Mines data. Inflation, increasing government regulations, etc. are causing a rapid rise in these costs.

I. Labor Requirements: ±250-300 miners for mines in the 0.9 - 1.0 mtpy range.

J. Surface Equipment: Most underground mines in the fields are expected to require on-site crushers, sizers and loadout facilities. Most steam coal from this field requires no washing. In addition, coking coal mines will require washing and thermal drying facilities, either on-site or in the vicinity.

K. Proximity to Transportation: The field is handy to the D&RGW mainline; most mines should be within ±10 miles of this line, or an existing or planned spur.

L. Common Transportation Mode: Conveyor belts and/or trucks to rail loadout facilities, where unit trains generally will load and ship.

M. Community Infrastructure Requirements: Established communities, with trained manpower, exist within reasonable commuting distances. Electric power lines and/or natural gas pipelines exist within a few mines of most present or planned mining operations in the field.

II. GENERAL MINING CONDITIONS

A. Structural Attitudes: Coal beds in the field generally dip from 4-8°, with a maximum of ±15°.

B. Topographic Relief: Mostly highly dissected; mine entries typically are made at coal outcrop areas in canyon walls (drift or slope mines).

C. Maximum Overburden: With present technology, ±2,500 - 3,000 ft, maximum; this factor limits the width of the field to about 4-5 miles.

D. Market: The steam coal market offers the greatest potential for coal produced from this field, both for new power plants planned for central Utah, and sales to Midwestern (i.e., Indiana, Michigan utilities, for examples. Little growth potential for metallurgical-grade coal exists here, at least in the short term. Present and proposed coking coal mines are captive, owned by U.S. Steel and Kaiser Steel.

III. TYPICAL COAL BED CHARACTERISTICS

A. Analyses, as received:

1. Steam coal: Approximately 12,500 - 13,000 Btu/lb, 0.4-0.6% sulfur, 5.7-6.3% ash, 3.9-6.8% moisture, 44-45% volatile matter, 48.7-49.3% fixed carbon.*

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*Drill-core samples tested by the Utah Geological Survey contained a field moisture range of from 1.2 to 4.7 percent, an ash range of from 3.0 to 20.8 percent, with an average of 6.3 percent, and a Btu range of from 10,728 to 13,902 Btu's/lb with an average of 13,205 Btu/lb.

2. Coking coal: Approximately 12,650 - 13,000 Btu/lb, 0.5-1.0% S, 6-7% ash, 5-7% moisture, 38-42% VM, 48-50.5% FC. Some samples exceed 14,000 Btu/lb on an as received basis.*

B. Thickness of Coal: ±4 to 14 ft; most mining today is in the ±6 to 8 ft minimum, ±12 ft maximum thickness.

C. Mining Problems: Some problems with methane emissions ("gassy coal beds"), especially with the higher-rank coals (i.e., coking grade). Water in mines generally presents no problems in this field. Roof and floor conditions generally are fair to good.

UINTA COAL REGION - WASATCH PLATEAU COAL FIELD

Wasatch Plateau Coal Field:

This field has produced approximately 140.5 million tons of coal to date or 36.5 percent of the State's total production. In 1979, the field was the largest producer in Utah, mining more than 70 percent of the State's 12 million tons from 17 mines (production in 1979 was 8,525,000 tons). Projected production for 1980 is 10 million tons; 1985 will see a rise to 13-17 million tons; 1990 project production is expected to reach 17-25 million tons. Original reserves for the field, in beds more than 4 ft thick and under less than 3,000 ft of overburden, have been estimated at 6.4 billion tons. More than 20 coal beds greater than 4 ft in thickness exist in the field. The coal beds here generally are gently dipping but are cut by numerous faults. Mining problems in the field, all of which have been successfully overcom by skilled operators, include thick overburden, faulting, burned coal, water entry, etc. The northern part of the field is served by several railroad spurs.

Coal produced from the southern part of the field is trucked either 25 miles to the west to the D&RGW spur line at SALINA or 80 miles to a mainline of the UPRR at a unit train loader 4 miles west of LEVAN.

1. Representative Mining Operations (only underground mines of more than +200,000 tons per year capacity should be considered in this model, due to high costs of mining in the field).

A. Coal Rank: bituminous (generally high volatile B or C).

B. Minimum Leasehold Required: Est. 2,000 - 3,000 acres in the southern portion of the field. In the northern portion of the field where transportation is less of a problem and the coal quality is better, the minimum leasehold requirement is 1000 acres, including federal, private, and state lands. This minimum leasehold requirement is based on a 12-foot coal bed. For a coal-bed that is 6-feet in thickness the land required would be increased to 1800 acres.

Channel samples tested by the Utah Geological Survey in the Sunnyside mine contained moisture ranges from 1.4 - 4.5 percent and averaged 2.4 percent. Ash ranged from 1.7 to 31.1 percent and averaged 8.7 percent. Btu ranged from 9789 to 14,435 and averaged 13,099. (Correspondence with Hellmut Doelling, Utah Geological and Mineral Survey, March 21, 1980.)

C. Minimum Recoverable Reserves Required: ±10 to 30 million tons (±30 - 35% recovery).

D. Mine Life: 20 to 30 years.

E. Coal Price, FOB Mine: $20-25 today.

F. Design Capacity: ±200,000 to 1 million tons per year (tpy), or larger.

G. Mining Technology: Continuous miners/room and pillar mining. Longwall mining is now operative in the Wasatch Plateau and (except in the faulted areas) should be as effective a mining method as in Book Cliffs field.

H. Capital Requirements: Approximately $35-40 million (±20%) for an underground mine of 1 million tpp capacity.

I. Labor Requirements: ±300 miners for mines with a ±1 million tpy capacity.

J. Surface Equipment: Crushers/sizers, loadout facilities; possible conveyor belts, depending upon accessibility to rail spurs.

K. Proximity to Transportation: Within ±5-10 miles of existing or planned rail spur. Conveyor belts may be preferable to truck haulage to rail lines due to relatively rugged topography, weather conditions, etc.

L. Common Transportation Mode: Conveyor belts, trucks, unit trains.

M. Community Infrastructure Requirements: Established communities with trained manpower (e.g., Helper and Price) exist within reasonable commuting distance. Electric power lines and/or natural gas pipelines are present in the field.

II. GENERAL MINING CONDITIONS

A. Structural Attitudes: Coal beds generally are of gentle (±5°) dip, cut by systems of mostly north-south faulting.

B. Topographic Relief: Wasatch Plateau is characterized by rugged, dissected surfaces with elevations ranging up to 10,000 ft or more.

C. Maximum Overburden: ±2,500 - 3,000 ft with present technology.

D. Market: Primarily steam coal for electric power plants in Utah, Nevada, and Arizona and occasionally in midwest (86 percent for power generation), and for industrial markets in the western states (10 percent) and for space heating (4 percent).

III. TYPICAL COAL BED CHARACTERISTICS

A. Analyses, as received (steam coal): 12,200 - 12,744 Btu/lb, 0.59-0.64% sulfur, 6.1-6.7% ash, 5.4-7.2% moisture, 41.4-42.4% volatile matter, 45.3-45.5% fixed carbon.

B. Thickness of Coal: ±4-24 ft; most mining will be in +6-12 ft range.

C. Mining Problems: Special precautions may be necessary due to thick overburden in some areas, faulting, possible water problems, some burned coal, some "bad rock" and seam splits, occasionally variable bed dips.

UINTA COAL REGION - EMERY COAL FIELDS

This field is located at the south end of the Wasatch Plateau. It has experienced limited development, in part because of the lack of nearby rail lines. Small amount of production in recent years must be trucked ±40-50 miles west to Salina or ±50-60 miles north to Pirce. In 1979 the field produced about 732,000 tons of coal from two underground mines, one using the conventional (undercut and blast) mining method and the other, continuous miners. Total production from the field is 4.3 million tons. Recoverable reserves in the field have been estimated at from 630-900 million tons, of which ±140 million tons are potentially surface-minable; ±76% of the reserves lie under less than 1,000 ft of overburden.

I. Representative Mining Operations (limited amount of information available due to small scale of development)

A. Coal Rank: Bituminous.

B. Minimum Operating Acreage: Unknown, probably at least 2,500 acres.

C. Recoverable Reserves Base: Probably 20-30 million tons.

D. Average Operating Mine Life; 25-30 years.

E. FOB Mine Price: Est. $20-25, today.

F. Design Capacity: At least 0.5-1.0 million tons per year, either surface or underground.

G. Mining Technologies: Underground - continuous miner; trend toward surface mining, possibly with truck and shovel, e.g., a 1 million tpy surface mine has been proposed to serve Midwest market.

H. Capital Requirements: Underground mine, $35-40 (±20%) million for 1 mtpy mine. Surface mine, $15-20 million (+20%) for a 1 mtpy mine.

I. Labor Requirements: Underground mine, 1 mtpy, est. 280-300 miners. Surface mine, 1 mtpy, est. 50-100 miners.

J. Layout: Crushing/sizing plant, loadout facilities.

K. Proximity to Transportation: Railroad will have to be constructed into field area before large-scale mining will develop. Nearest rail lines now are ±40-50 miles away.

L. Common Transportation Mode: Unit trains.

M. Community Infrastructure: Field is relatively remote. Living and service facilities may have to be built closer to mines.

II. GENERAL MINING CONDITIONS

A. Structural Limits: Most coal beds dip 4° - 7°, maximum 12°. Only minor faulting known to exist in field.

B. Regional Relief: Erosional escarpment on east allows mine entry at outcrop.

C. Maximum Operating Depth: Probably ±1,000 ft of overburden for underground mines; est. 50-100 ft for surface mines.

D. Market. In 1979 the field produced over 700,000 tons, 42,8 percent went to Nebraska for power generation; 45.8 percent went to Wyoming, Idaho and California for industrial purposes and 11.5 percent was utilized in Utah and Idaho for space heating. Could be prime candidate for IPP electric power generation or for synfuels.

III. TYPICAL COAL BED CHARACTERISTICS

A. Analyses, as received (stem coal): 11,424 - 12,338 Btu/lb, 0.31-4.6% (mostly 0.5-2.5%) sulfur, 8.9-9.6% ash, 7.4% moisture, 38-41% volatile matter, 45.7-49.4% fixed carbon. Coal bed quality diminishes from a high volatile B bituminous in the north to a subbituminous A coal to south.

B. Thickness of Coal: 6 coal beds in 4-12 ft range; 6-8 ft probably minimum thickness for mining, either underground or surface.

C. Mining Problems: Some undulating beds, some roof and floor problems.

SOUTHWESTERN UTAH COAL REGION - KAIPAROWITS PLATEAU COAL FIELD

This largely undeveloped coal field contains more than 30 percent of Utah's coal reserves, with some 7.9 billion tons; potential resources may exceed 30 billion tons. Past coal production totals less than 25,000 tons. No mining is taking place in the field at the present time. Although coal from this field is of somewhat lower quality than that from the Book Cliffs or Wasatch Plateau fields, nevertheless it is low in sulfur content and of comparatively high quality, being mostly of bituminous rank.

I. REPRESENTATIVE MINING OPERATIONS (large underground mines only)

A. Coal Rank: Subbituminous C to high-volatile A bituminous (steam coal).

B. Minimum Operating Acreage: Probably 5,000 - 10,000 acres.

C. Recoverable Reserve Base: Est. ±70 to 150 million tons.

D. Average Operating Mine Life: 25-30 years.

E. FOB Mine Price: Est. $20/ton, current.

F. Design Capacity: ±0.5-1.0 million tons/yr, minimum, underground only.

G. Mining Technologies: Underground - continuous miner/room and pillar, possibly longwall in some instances.

H. Capital Requirements: $40 million (±20%) for 1 mtpy mine (underground).

I. Labor Requirements: Est. 250-300 miners for 1 mtpy mine.

J. Layout: Crushing/sizing plant, loadout facilities.

K. Proximity to Transportation: Presently, ±100 miles from nearest main rail line. Rail service would have to be constructed into area if coal is to be exported out of field.

L. Common Transportation Mode: Probably unit trains.

M. Community Infrastructure: Remote area, far from even small established communities (Mormon). Some power transmission lines around periphery of field.

II. GENERAL MINING CONDITIONS

A. Structural Attitudes: Coal beds in the field are of low dip (presumably, less than 5°); faulting is scattered and presents no problem.

B. Topographic Relief: The terrain is difficult from the access standpoint; the plateau area is highly dissected.

C. Maximum Overburden: Probably ±1,000 ft; much of the southern part of the field is under less than 800 ft of cover.

D. Market: Probably steam-electric power plants in the region. Utah Power & Light Co. has proposed a 2,000 MW coal-fired plant in southern Utah. The coal for this plant will come from their existing leases on the Kaiparowits Plateau.

III. TYPICAL COAL BED CHARACTERISTICS

A. Analyses, as received: 11,207 - 12,401 Btu/lb (average +12,000); 0.75-1.26% sulfur (average ±0.87); 7.8-13.8% ash (average ±9%); 9.6-19.5% moisture (average ±11.3); 42.5-45.4% volatile matter (average ±43.6); 41.8-48.8% fixed carbon (average ±47.3).

B. Thickness of Coal: Variable, up to ±25 ft, often separated by thin rock partings; 3-5 generally thick but discontinuous coal zones, often highly lenticular. Probably only ±12 ft maximum could be underground-mined in a single coal bed.

C. Mining Problems:

1. Coal beds discontinuous, lenticular, difficult to correlate; multiple beds, often thick.

2. Areas of extensive burned coal; some surface and subsurface collapse problems.

3. Undulating roof.

4. Possible water problems from massive sandstones occurring within coal-bearing sequence.

5. Relatively high mining costs, difficult terrain, remote area, many unknown factors.

6. Opposition from environmental groups due to proximity of area to National Recreation Areas, etc.

SOUTHWESTERN UTAH COAL REGION - ALTON COAL FIELD

This field covers about 175 sq mi, is approximately horseshoe-shaped, and surrounds the Paunsaugunt Plateau. Alton coal field abuts against the Sevier fault on the west and extend to Bryce Canyon National Park on the east. The Kaiparowits Plateau coal field adjoins Alton on the east. No coal mines presently are active in Alton field, which, historically, has produced less than 50,000 tons of coal since mining began in the area in the 1870's. The area still is sparesely populated and relatively isolated. Surface-minable coal reserves in Alton field are estimated at 200-400 million short tons; total resources may exceed 2 billion tons, although data are incomplete. Elevations in the field vary from 5,500 to 9,400 ft. The topography is mostly bench-and slope, with a few, small, perennial streams. The climate is arid, from 5 to 20 inches annually, depending on elevation.

I. REPRESENTATIVE MINING OPERATIONS (large surface mine only)

A. Coal Rank: Subbituminous B and C (steam coal).

B. Minimum Operating Acreage: Est. 8,000 - 10,000 acres.

C. Recoverable Reserve Base: 100 to 200 million tons, in-place (recovery factor est. 90-94%).

D. Average Operating Mine Life: 25 years.

E. FOB Mine Price: Est. $12-15/ton, current.

F. Design Capacity: 10-11 million tons/yr.

G. Mining Technologies:

1. Overburden less than 50 ft: Shovels, front-end loaders, 85-ton dump trucks.

2. Overburden greater than 50 ft: 60-cu yd draglines (electric) down to 100 ft; and front-end loaders below 100 ft.

H. Capital Requirements: $15-20 million (±20%) for 1 mtpy surface mine.

I. Labor Requirements: ±600 to 700, including ±85 construction force for first 8 yrs of operation, for 10-11 mtpy surface mine.

J. Layout: Coal trucked to preparation plant for crushing and slurrying.

K. Proximity to Transportation: Field is 50 miles from UPRR at Cedar City, Utah; and 70 miles from D&RGW line at Marysvale, Utah.

L. Common Transportation Mode: Proposed coal-water slurry pipeline to carry coal to proposed electric power plants near St. George, Utah, and Las Vegas, Nevada, part of Allen-Warner Valley Energy System (2,000 MW Harry Allen Station, ±25 mi northwest of Las Vegas; and 500 MW Warren Valley Station, ±13 mi southeast of St. George). Participants would be Nevada Power Co., Los Angeles Department of Water & Power, and City of St. George, Utah.

M. Community Infrastructure: Remote area, far from population centers; Kane and Garfield Counties, together, total approximately 5,000 in population. Bryce Canyon National Park is nearby. No high-voltage service to the area at present.

II. GENERAL MINING CONDITIONS

A. Structural Attitudes: Coal beds in the field are of low dip (est. 5° or less); broad gentle syncline in area; east and west boundaries of field bounded by north-south striking faults ith throws varying from ±100 - 2,000 ft. Some igneous intrusive bodies are present in the area.

B. Topographic Relief: Irregular topography, with delicate erosional features (as in Bryce Canyon National Park, nearby); some slopes approach the verticle along the Paunsaugunt Plateau escarpments; elevations range mostly from 6,500 - 7,200 ft.

C. Maximum Overburden: ±150 ft.

D. Market: Steam-electric power plans in region (see I-L, above).

III. TYPICAL COAL BED CHARACTERISTICS

A. Analyses, as received (average in area): 9,647 Btu/lb; 1.11% sulfur; 9.34% ash; 17.27% moisture; 33.25% volatile matter, 39.93% fixed carbon.

B. Thickness of Coal: Mostly 12-14 ft (1 main minable bed), with a few rock splits; some deeper coals (up to 4 closely spaced seams) that average 5-6 ft, but are lenticular and badly split with rock partings.

C. Mining Problems:

1. Some splits and partings in coal beds may require special mining techniques in a few areas.

2. Some burned/clinkered coal in area.

3. Area characterized by a high degree of erodability, which will require special mining and reclamation techniques.

4. Ground water may be encountered within the pit areas in some cases; however, this water can be used to supress dust on the access roads, etc.

5. Strong opposition from evironmental groups due to area's close proximity to Bryce Canyon National Park.

MODEL FOR SMALL LUMP COAL MINE IN UTAH

The small towns of central and southern Utah still use a certain amount of coal for space heating purposes. The use of coal for space heating and for fireplace coal is one the rise because of the recent price increases for power, gas, and heating oil. Several mines produced such coal in Utah through 1972 when stiff mine safety regulations could not be met without making the whole operation uneconomical. The current rise in heating prices has sparked many inquiries about the feasibility of opening such mines again; recently the market has been only partially met by larger mines who carry such business as a sideline and drop it when their other business keeps them running at capacity. Presently Utah could support one lump coal mine in each geographical market area, i.e., central Utah, southern Utah, perhaps eastern and northern Utah. Coal would be picked up directly by the customers in light trucks if the mine is within 100 miles of the home or would be delivered by semi to the coal yard.

I. Representative Mining Operations (presently there are none, in 1978 one such mine produced 5,000 tons. These mines would operate seasonally and intermittently and would produce 1,000 to 15,000 tpy.

   A. Coal Rank: Coal rank is less important in the lump coal market. However, the coal must be minable as lump, contain less than 10 percent ash and less than 1 1/2 percent sulfur.

   B. Minimum Leasehold Required: Perhaps 40 acres would be a minimum. If rental costs are a problem for the operator, the smaller property would be more favorable.

   C. Minimum Recoverable Reserves Required: 100,000 tons

   D. Mine Life: 5 or more years.

   E. Coal Price, FOB mine $35-50, yard 45-100 per ton.

   F. Design Capacity: Up to 20,000 tpy.

   G. Mining Technology: Undercut and blast, conventional mining.

   H. Capital Requirements: $10,000+ much ingenuity, scrounging, salvaging and in-house mechanical ability and inventiveness.

   I. Labor Requirements: Operator and 1 or 2 miners.

   J. Surface Equipment: Loading facility or front-end loader. Can be self-built or used.

   K. Proximity to Transportation: Best near a paved road with a short gravel spur to the mine. Should be within 100 miles of homes or building to be served (100 miles from customers home), hopefully less than 50 miles for most customers. Should be within 200 miles for semi-loads.

L. Common Transportation Mode: Light and heavy trucks; short conveyor belts, front-end loader.

M. Community Infrastructure Requirements: None: Fuel requirements may require an on-site large tank. Miners could live in trailers. Most customers should live within 50 miles, all within 100 miles--market should be within 200 miles.

II. General Mining Conditions:

A. Structural attitudes: Best if beds are gentle, but if minimum reserve is present along strike attitude is of no consequence. Bad faulting and roof conditions and other uncontrollable situations would eliminate the viability of this mine.

B. Topographic Relief: Best close to the outcrop, must have a surface portal in coal.

C. Maximum overburden: Best between 500 and 1500 ft of overburden, less OK with good roof.

D. Market: Primarily space heating.

III. Typical Coal Bed Characteristics:

A. Analyses, as received should exceed 10,000 Btu/lb., contain less than 1.5 percent sulfur and contain less than 12 percent ash (8 percent or less would be preferred). The presence of resins would enhance the coal. Wasatch Plateau coals are full of resins which allow the fireplace coal to be easily ignited. Cannel coal is also preferred even at the expense of higher ash and sulfur--Orderville Area of Kolob Field.

B. Thickness of Coal: Best greater than 6-foot beds for comfort of miners; excessive height unimportant. A limited amount of splitting can be handled by selective mining, i.e., a split dividing the coal into two benches could be handled, but a series of thin splits, which a mine with a washery could handle, could not be handled competitively.

C. Mining Problems: Excessive discontinuities (splits, spar, faulting, lenticularity) would eliminate the property from this sort of mining. In addition local areas with heavy water flow, bad roof, heaving floor, would be eliminated. The ingenuity of the operator to comply with safety regulations will weigh heavily on this ability to produce successfully.

IV. Miscellaneous Factors:

A. Leaseholder experience, business ability, ingenuity, and goals will be as important as the favorable geologic conditions. It will be a risky venture and will best succeed where the work is seasonal and done as a sideline to other employment.

B. Location: This item is partially covered in IK (Proximity to transportation), but the closer to market, the one on the better road will have a more advantageous situation.

C. The coal fields which could each support one such mine are the Wasatch Plateau, Book Cliffs, Emery, Coalville and Sego. Sego has very thin coal beds--4-6 ft, but are closest to the Moab-Monticello-Blanding market. All of southwestern Utah could support two such operations--1 in the Kaiparowits near Escalante, which would support areas from Bryce Canyon eastward and 1 in the Alton-Orderville area to support areas to the west. The Cedar City area of the Kolob field could not compete because of the high ash and high sulfur there.

CRITERIA FOR CHARACTERIZING COAL MINES IN THE WESTERN UNITED STATES

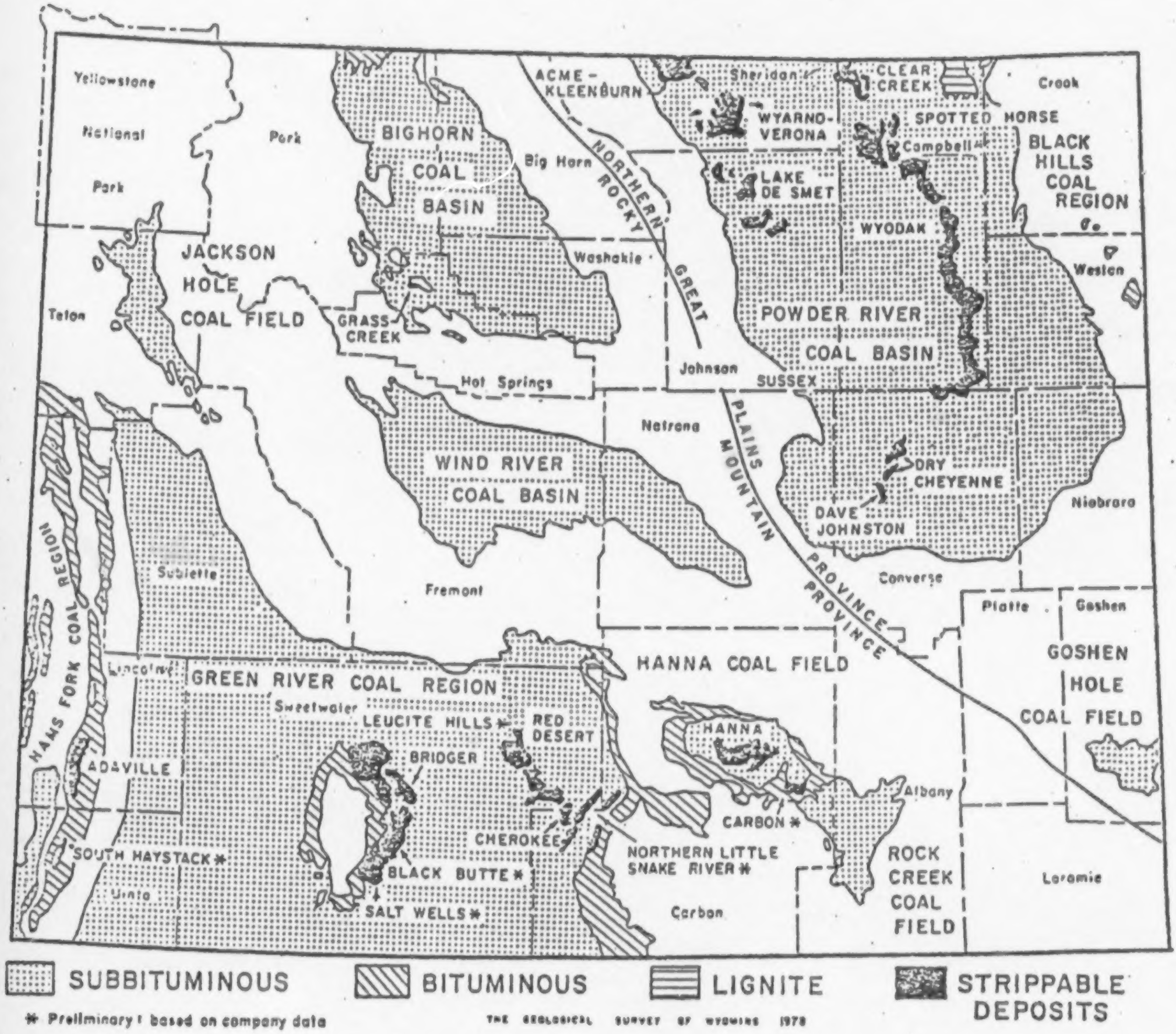
CONVENTIONAL MINE DEVELOPMENT MODEL

WYOMING

GENERAL STATEMENT

The estimated, original in-place coal resources of Wyoming for explored and mapped areas are 136,891.4 million short tons. This includes beds of bituminous coal 14 in. or more thick and beds of subbituminous coal 2.5 ft or more thick, both beneath 3,000 ft or less of overburden. This estimate includes only 46.54% of the State's known or probable coal-bearing land; when the remainder of this land is considered, the estimated, original in-place coal resources are 836,891.4 million tons. For all of these lands, to a depth of 6,000 ft, the estimated original resources are 936,891.4 million tons. This is almost 24% of the Nation's coal resources to that depth. As of January 1, 1978, only about 1,024.86 million tons of coal had been produced or lost through mining. The estimated reserve base of coal in mapped and explored areas of Wyoming, including beds of bituminous coal 28 in. or more thick and beds of subbituminous coal 5 ft or more thick to depths of 3,000 ft, is 55,763.66 million tons. Of this reserve base about 26,275.40 million tons are strippable. The estimated original resources in mapped and explored areas were about 94% subbituminous coal, 4% bituminous coal, and 2% lignite.

The coal resources of Wyoming underlie more than 40,000 square miles, amounting to about 41% of the area of the State. The coal occurs in ten widespread, major basins, regions, and fields. These have been subdivided, based on geology and the distribution of mining activity, into 45 fields. The major coal-bearing areas, in decreasing order of estimated resources, are as follows:


Yellowstone
National
Park
Park
BIGHORN
COAL
BASIN
Big Horn
ACME-
KLEENBURN
NORTHERN
ROCKY
GREAT
PLAINS
MOUNTAIN
PROVINCE
PROVINCE
Sheridan
CLEAR
CREEK
Crook
WYARNO-
VERONA
SPOTTED HORSE
Campbell
BLACK
HILLS
COAL
REGION
LAKE
DE SMET
WYODAK
Washakie
Weston
JACKSON
HOLE
COAL FIELD
Teton
GRASS
CREEK
POWDER RIVER
COAL BASIN
Johnson
SUSSEX
Hot Springs
Natrona
WIND RIVER
COAL BASIN
DRY
CHEYENNE
Niobrara
DAVE
JOHNSTON
Sublette
Fremont
Converse
Platte
Goshen
HAMS FORK COAL REGION
GOSHEN
HOLE
COAL FIELD
HANNA COAL FIELD
Lincoln
GREEN RIVER COAL REGION
Sweetwater
LEUCITE HILLS *
RED
DESERT
HANNA
BRIDGER
ADAVILLE
Albany
CARBON *
CHEROKEE
NORTHERN LITTLE
SNAKE RIVER *
SOUTH HAYSTACK *
BLACK BUTTE *
ROCK
CREEK
COAL
FIELD
Uinta
SALT WELLS *
Carbon
Laramie
SUBBITUMINOUS
BITUMINOUS
LIGNITE
STRIPPABLE
DEPOSITS
* Preliminary: based on company data
THE GEOLOGICAL SURVEY OF WYOMING 1978

Wyoming Coal-Bearing Areas.

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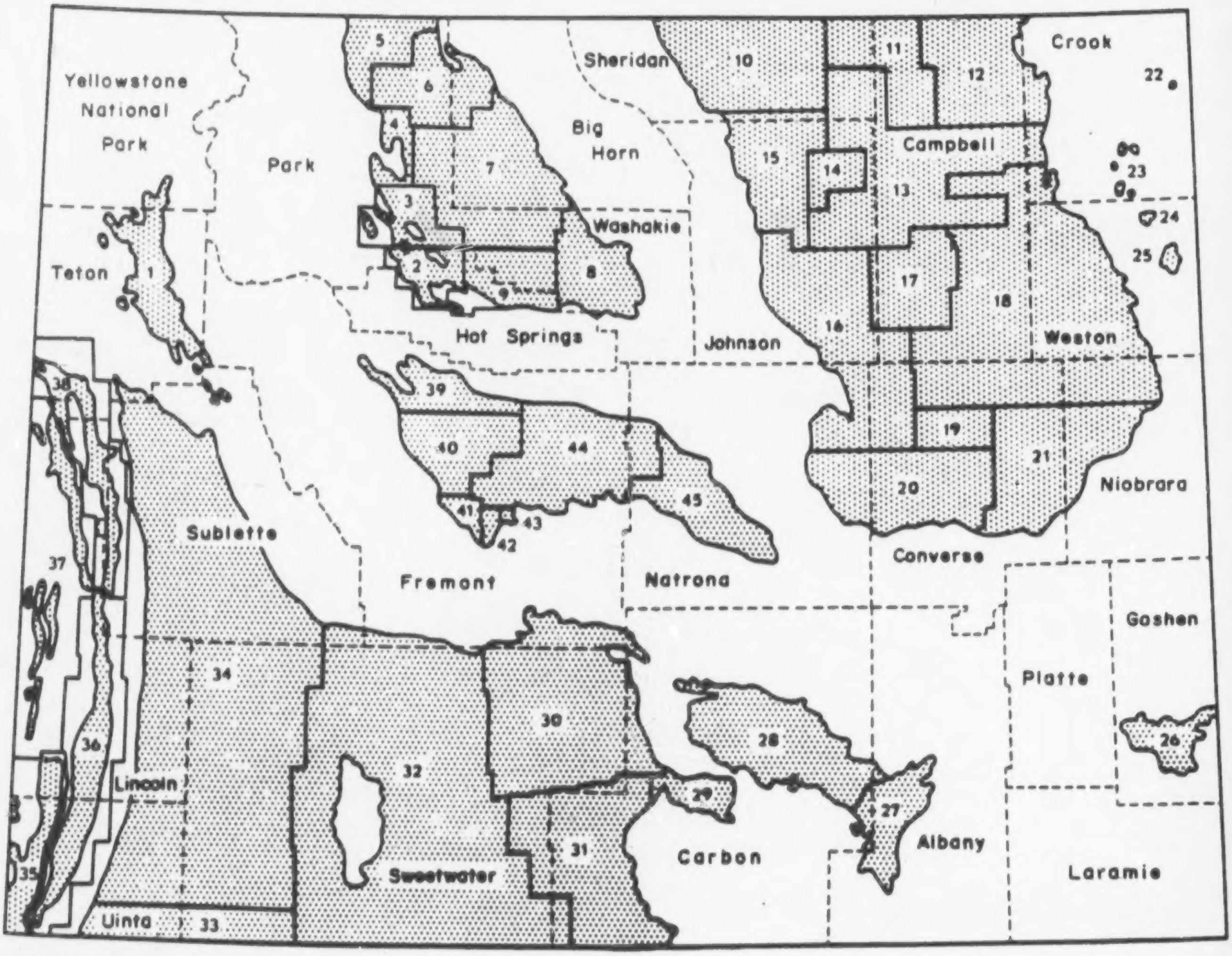
Yellowstone National Park
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Washakie
Hot Springs
Johnson
Weston
Niobrara
Sublette
Fremont
Natrona
Converse
Goshen
Platte
Lincoln
Sweetwater
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1. Jackson Hole
2. Grass Creek
3. Meeteetse
4. Oregon Basin
5. Silvertip
6. Garland
7. Basin
8. Southeastern
9. Gebo
10. Sheridan
11. Spotted Horse
12. Little Powder River
13. Powder River
14. Barber
15. Buffalo
16. Sussex
17. Pumpkin Buttes
18. Gillette
19. Dry Cheyenne
20. Glenrock
21. Lost Spring
22. Aladdin
23. Sundance
24. Skull Creek
25. Cambria
26. Goshen Hole
27. Rock Creek
28. Hanna
29. Kindt Basin
30. Great Divide Basin
31. Little Snake River
32. Rock Springs
33. Henry's Fork
34. Labarge Ridge
35. Evanston
36. Kemmerer
37. Greys River
38. McDougal
39. Muddy Creek
40. Pilot Butte
41. Hudson
42. Beaver Creek
43. Big Sand Draw
44. Alkali Butte
45. Arminto

Coal Fields of Wyoming

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1. Powder River coal basin (12 fields).
2. Green River coal region (6 fields).
3. Ham's Fork coal region (4 fields).
4. Hanna coal field (1 field).
5. Wind River coal basin (7 fields).
6. Bighorn coal basin (8 fields).
7. Rock Creek coal field (1 field).
8. Jackson Hole coal field (1 field).
9. Black Hills coal region (4 fields).
10. Goshen Hole coal field (1 field).

The recent production and estimated original in-place resources of the areas are summarized in Table 1.

The Powder River basin, Black Hills region, and Goshen Hole field lie in the Northern Great Plains coal province. The remainder of the coal-bearing areas lie in the Rocky Mountain coal province. Coal occurs in formations ranging in age from Early Cretaceous to Eocene, although the most widespread coal-bearing formations were deposited in the Late Cretaceous and Eocene. Many of the coal-bearing formations or groups occur in more than one area and even span the division between the two major coal provinces in the State.

Mining Method: Coal mining in Wyoming began in the mid-Nineteenth century, and until 1954 underground mining predominated. Through January 1, 1978, underground-mined coal accounted for 65% of Wyoming's total historic production. The rate of production by surface mining has now far outstripped that of underground mining, however. In 1976 and 1977, surface mines accounted for more than 98% of Wyoming's annual production. Future energy projects in Wyoming include 51 planned or proposed new or expanded surface mines and only seven planned or proposed new or expanded underground mines, with two combined surface and underground mines (Tables 2 and 3).

TABLE 1

Recent Production and Estimated Original In-Place Coal Resources of Coal-Bearing Areas in Wyoming

(Data from Glass, 1978)

Coal Producing Region	1976 Production		1977 Production		Estimated Original In-Place Coal Resources (in explored and mapped areas) (10^6 tons)		
	Number of Mines	Coal Produced (10^6 tons)	Number of Mines	Coal Produced (10^6 tons)	Bituminous	Subbituminous	Total
Powder River Basin	5 strip	11.526	7 strip	23.017	0	110,218.95 (includes a small amount of lignite)	110,218.95
Green River Region	1 strip 2 deep	3.787	1 strip 2 deep	5.684	9,904.84	6,051.04	15,955.88
Ham's Fork Region	3 strip	4.208	3 strip	5.103	3,197.68	1,676.86	4,874.54
Hanna Field	5 strip 1 deep	11.554	5 strip 1 deep	10.196	73.44	3,843.52	3,916.96
Wind River Basin	0	0	0	0	0	875.66	875.66
Bighorn Basin	1 strip	0.002	1 strip	0.002	17.90	563.76	581.68
Rock Creek Field	0	0	0	0	0	305.18	305.18
Jackson Hole Field	0	0	0	0	0	121.49	121.49
Black Hills Region	0	0	0	0	41.09	0	41.09
Goshen Hole Field	0	0	0	0	0	not estimated	not estimated
Total (may not add precisely because of rounding)	14 strip 3 deep	31.085	16 strip 3 deep	44.046	13,234.95	123,656.48	136,891.43

TABLE 2

Size of Projected Surface Mines in Wyoming

(Data from Department of Energy, 1980)

(Including combined underground and surface mines)

	Number of Mines			Design Capacity (millions of tons per year by 1990)					
Coal-Producing Area	Producing in 1979	On-Line after 1979	Total	<1	1-4.9	5-9.9	10-14.9	15-19.9	>20
Powder River Basin	12	15[1]	27	2	2	5	10	2	2
Green River Region	2	11	13	2	9	2	0	0	0
Ham's Fork Region	3	2	5	0	5	0	0	0	0
Hanna Field	5	1	4[1]	0	4	0	0	0	0
Wind River Basin[2]	0	3	3	1[3]	0	0	0	0	0
Bighorn Basin	1	0	1	1	0	0	0	0	0
Total	22	32	52	6	23	7	10	2	2

[1] Includes unpublished data for one mine planned to produce less than 0.2 million tons per year.

[2] Does not include two mines that plan to cease production before 1990.

[3] Unpublished data from D.O.E.

[4] Design capacities are unplanned for two of the three mines.

TABLE 3

Projected Design Capacities for Annual Production from Underground Coal Mines in Wyoming

(Data from Department of Energy, 1980)

(Does not include combined surface and underground mines)

Coal-Producing Area	Number of Mines			Design Capacity (millions of tons per year by 1990)			
	Producing in 1979	On-Line after 1979	Total	0-0.5	0.6-1.0	1.1-1.5	1.6-2.0
Green River Region	1	2	3	0	0	2	1
Ham's Fork Region	0	1	1	1	0	0	0
Hanna Field	2	1	3	0	1	2	0
Total	3	4	7	1	1	4	1

Mine Size: Data on actual trends for surface mines in recent years and projected trends through 1990 both indicate that statewide the predominant size of surface mines, in terms of production, will be in the range of approximately 1.0 to 5.0 million tons per year (tpy), but that the proportion of larger mines will increase (Tables 2 and 4). Data from recent years show that a substantial proportion of the mines have produced in the past at a lesser rate (Table 4). However, this primarily reflects the start-up of new mines that will expand their capacities, and by 1990 the proportion of mines producing at less than 1 million tpy will decline. Nineteen of the 21 mines that are projected to be producing more than 5 million tpy will be in the Powder River coal basin, and two will be in the Green River coal region. The Powder River coal basin is the only area where most of the mines will be producing at rates of more than 5 million tpy (Table 2).

Underground Mines: In 1977, production was recorded from only three underground mines. Two of these mines, which produced 0.230 and 0.388 million tons, accounted for about 99% of the total underground-mined coal production of the State. Over the next decade, four new mines will begin producing, and existing mines will expand. Ultimately, most of these mines will produce at rates of from 1.1 to 1.5 million tpy (Table 3).

Utilization: In 1977, about 67% of Wyoming's coal production was shipped out-of-state to steam-electric power plants, and another 26% was used within the State for the same purpose. The remaining 7% went to industrial users and was about equally divided between in-state and out-of-state consumers. Some of this coal was used in two coking facilities in Wyoming.

Wyoming's coal was shipped to power plants in 19 states in 1977, including all of the Western states except California, all of the Great Plains states down to and including Texas, and all of the northern Midwestern states as far east as

TABLE 4

Production of Surface Mines in Recent Years for Mines Producing at a Substantial Proportion of Design Capacity

(millions of tons)

Year	<1.0	1.0-4.9	5.0-9.9	10.0-14.9	15.0-19.9	>20	Total
1977	4	11	1	1	0	0	17
1979[1]	5	12	4	0	0	1	22

[1] Includes only mines that produced 0.2 million tons or more.

Ohio, with the exception of Michigan. Future markets may include California, Kentucky, and the Southern states as far east as Georgia and Florida.

The greatest future demand for Wyoming's coal will derive from electric utilities, both in-state and out-of-state. Additionally, a large in-state demand may develop for coal for feedstock for high-Btu gasification plants.

COAL CHARACTERISTICS

Typical characteristics of coal in different geographic areas of the state are summarized in Table 5.

Rank: Coal in Wyoming ranges in rank from lignite to high-volatile A bituminous. Of the estimated, original, in-place coal resources of explored and mapped areas of Wyoming, 4% were bituminous, 94% were subbituminous, and 2% were lignite. When the resources of currently unexplored areas are evaluated, it will probably be found that they include a higher percentage of bituminous coal, because these areas generally comprise the deeper parts of the coal-bearing basins.

The amounts of estimated, original, in-place coal resources of different ranks in the mapped and explored areas of Wyoming are summarized in Table 1. Of these resources, all of the lignite and about 85% of the subbituminous coal are found in the Powder River basin. Almost 99% of the bituminous coal resources are found in the Green River and Ham's Fork regions, and in these two areas bituminous coal predominates. Small amounts of bituminous coal also occur in the Hanna field, Bighorn basin, and Black Hills region.

In Wyoming, all of the known bituminous coal occurs in Cretaceous-age formations, all of the subbituminous coal is in Late Cretaceous or Tertiary formations, and all of the lignite is in Tertiary formations. In any given field, the rank of a coal generally varies as a function of depth of burial. In a given stratigraphic section, the deeper, older beds tend to be of higher rank. Within a given bed, rank tends to increase with depth toward the structural troughs.

TABLE 5

Wyoming Coal Characteristics

Geographic Area	Rank	Bed Thickness ft	Moisture[1] (AR) %	Ash[1] (AR) %	Sulfur[1] %	Heat Value (AR) Btu/lb	Hardgrove Grindability Index[1]
Northeastern Wyoming	Lignite Subbituminous[1] Bituminous	Max.: 220 Range[1]: 12-100 Avg.[1]: 70	Range 20.3-29.8 Average 26.3	Range 4.4-11.4 Average 7.9	Range 0.45-0.6 Average 0.54	Range 7,550-8,700 Average 8,300	Range 30-53 Average 45
Southern Wyoming	Subbituminous[1] Bituminous[1]	Max.: 50 Range[1]:4-35 Avg.[1]: 20	Range 10.2-20.5 12.4	Range 4.2-12.2 7.1	Range 0.4-0.9 0.52	Range 9,270-11,700 10,500	Range 45-80 49
Western Wyoming	Subbituminous[1] Bituminous	Max.: 110 Range[1]: 5-90 Avg.[1]: 16.5	Range 20.4-20.9 20.8	Range 3.0-4.8 4.5	Range 0.6-0.7 0.6	Range 9,500-10,200 9,600	Range 53-57 54
Northcentral Wyoming	Subbituminous[1] Bituminous	Max.: 50 Range[1]: 15-20 Avg.[1]: 13	Range 10.7-12.8 Average 12.3	Range 5.0-9.4 Average 7.4	Range 0.3-0.6 Average 0.4	Range 10,730-11,246 Avaerage 10,970	Range 30-80 Average 49

[1] Beds currently mined. (Table compiled by Geological Survey of Wyoming, March 1978.)
(AR) = As Received

Sulfur Content: More than 99% of the known coal resources of Wyoming contain less than 1% sulfur, and about half contain less than 0.7% sulfur. About 40% of the reserve-base coal contains less than 0.7% sulfur. Typically, 3% to 5% of the sulfur is in the form of sulfate, 25% to 29% is pyritic, and the remainder is organic.

The sulfur content of Wyoming's coal is related more to depositional history than to differences in rank. The highest sulfur contents, up to 7%, are reported from coals of the Eocene Wasatch Formation in the Green River region. However, as-received, Cretaceous coals usually show 0.9% to 2.0% sulfur, and Tertiary coals generally show 0.3% to 0.9% sulfur. The sulfur contents of coals that are typically mined average 0.5% and rarely exceed 1.0%. Values typical of different areas are presented in Table 5.

Heating Values: The heating values of Wyoming's coals vary widely but are appropriate for their ranks. Average as-received values range from 8,300 Btu/lb in the northeastern part of the State to 10,970 Btu/lb in the north-central part of the State. For typical heating values, see Table 5. On a moist, mineral-matter-free basis, the heating values of the bituminous coals range from 11,000 to 14,400 Btu/lb; and the heating values of the subbituminous coals range from 8,400 to 13,000 Btu/lb. It appears that the heating values of at least the subbituminous coals increase markedly with depth; and in the Hanna basin, increases of 300 Btu/lb for increases of 110 ft of overburden have been reported.

Moisture Content: The moisture contents of coal in Wyoming vary widely as a function of rank. As-received, the moisture contents of bituminous and high-rank subbituminous coals are similar and are generally less than 15%, whereas the moisture contents of low-rank subbituminous coals are typically 20% to 30% (see Table 5).

Volatile Matter: The volatile-matter contents of coals in Wyoming vary with rank. As-received, the volatile-matter contents of bituminous and high-rank subbituminous coals are 30% to 40%, whereas the volatile-matter contents of low-rank subbituminous coals are 20% to 30%.

Ash Content: In Wyoming, the ash contents of coals, like the sulfur contents, depend on depositional history rather than on rank. Minable coals from all regions of Wyoming generally contain less than 10% ash, although ash contents of more than 50% have been reported (see Table 5).

COAL CONVERSION

Gasification: Wyoming's thick beds of subbituminous coal appear to be well suited for in situ gasification, and Wyoming is the site of five previous or planned in situ gasification experiments. In addition, at least five coal conversion plants have been proposed in the Powder River basin alone.

Liquefaction: Wyoming's high-volatile bituminous coals may be suitable for liquefaction; however, at this time there are no plans for constructing coal liquefaction plants in Wyoming.

GREEN RIVER COAL REGION

The Green River coal region is the second largest coal-bearing area in the State of Wyoming, in terms of both estimated, original in-place coal resources and estimated, original and remaining strippable reserves. The total, estimated original in-place coal resources of the region are 15,955.88 million tons, almost 12% of the total for the State. Of the region's resources, 9,904.84 million tons are bituminous coal and the remaining 6,051.04 million tons are subbituminous coal (Table 1). The bituminous coal in the Green River coal region amounts to virtually three-quarters of the bituminous coal resources of the State. The coal-bearing formations of the Green River coal region are largely concealed by younger, noncoal-bearing rocks, and the total coal resources of the region are only poorly known.

The Green River coal region in 1977 had only one producing surface mine; however, this was the second largest mine in the State, producing 5,448,953 tons that year. Two small underground mines also operated in the region. By 1979, one additional surface mine had been added. In the coming decade the Green River coal region will be the second most actively developed coal-producing area, after the Powder River coal basin, and will be the only area outside of the Powder River coal basin with surface mines producing more than 5 million tons per year (tpy) (Table 2). The Green River coal region will also lead the State in production from underground mines, although these will be fewer in number and generally smaller in size than the surface mines (Table 3).

Because of the preponderance of surface mines and the general lack of data on underground mines, only surface mines will be considered in detail under Representative Mining Operations, and unless otherwise specified, only surface mines are referred to.

I. REPRESENTATIVE MINING OPERATIONS

A. Coal Rank: The estimated, original, in-place coal resources of the Green River coal region are 62% bituminous and 38% subbituminous.

B. Minimum Leasehold Requirement: For a minable reserve base of 20 million tons, which is probably the minimum that would be developed in light of typical annual production rates and mine lives, and for a bed thickness of from 10 to 30 ft, which are typical for the minable beds in the region, the minimum leasehold requirement is probably at least 1,200 acres.

C. Minimum Recoverable Reserves Requirement: Probably at least 20 to 30 million tons of recoverable coal are required for the development of a major mine, although the largest mines proposed for the area will require more than 100 million tons of recoverable reserves.

D. Mine Life: 20 to 30 years.

E. Coal Price, FOB Mine: Recent spot-market prices for coal from Wyoming with less than 1% sulfur have ranged from $7.25/ton for coal with 8,000 Btu/lb to $9.00/ton for coal with 9,000 Btu/lb. Prices on the regular contract market should be somewhat lower.

F. Design Capacity: The currently projected design capacities of new and expanding surface mines range from 0.5 to 6.8 million tons per year (tpy). Most of the projected surface mines will have capacities of 1.0 to 4.9 million tpy (Table 2). The three projected underground mines in this region will have capacities of 1 to 2 million tons, although smaller underground mines have operated here in the past.

G. Mining Technology: For surface mines, standard surface-mining equipment, probably centered around draglines and bucketwheel excavators. Data on underground mining techniques are not available for this region.

H. Capital Requirements: $15 to $20 million (±20%) for a surface mine producing 1 million tpy; $35 to $40 million (±20%) for an underground mine of the same size.

I. Labor Requirements: Data are available from only one surface mine, which had a ratio of 36.0 employees per million tons of coal produced in 1977. This ratio is comparable to ratios in the Powder River coal basin, which are the lowest overall for the three major coal-producing areas. Labor requirements for the Green River coal region should not be too dissimilar to those in the Powder River coal basin, and may be expected to average between 40 to 50 employees per million tons of coal produced annually. Data are not available for underground mines of the capacity to be developed, but data from other states suggests that the ratios may be several times higher for underground mines than for surface mines.

J. Surface Equipment: Surface mines will require such mining equipment as bucketwheel excavators, draglines, stripping and loading shovels, truck, front-end loaders, and dozers. In addition, both surface and underground coal mines may require haul roads, railroad spurs, conveyors, coal storage and loading facilities, support facilities, and offices.

K. Proximity to Transporation: The Green River coal region is not so well served by railroads as is the Powder River coal basin in Wyoming or coal-producing areas in Montana and North Dakota. Only a single main line of the Union Pacific Railroad serves this extensive region, passing east-west through the center of it. However, many of the proposed mines in the region would be projects involving Rocky Mountain Energy, which is a subsidiary of the Union Pacific Corporation. The general vigor of proposals for this area suggests that the current absence of an extensive railroad network is not a major obstacle to the development of coal resources.

L. Common Transportation Mode: Coal will probably be transported by both conveyors and trucks to railroad facilities for shipment on unit trains.

M. Community Infrastructure Requirements: The Green River coal region is not so widely settled as are the more developed coal-producing areas such as the Powder River coal basin. There may be some surplus of trained or general manpower in the region, but it is probably insufficient to supply future developments on the scale that is anticipated.

II. GENERAL MINING CONDITIONS

A. Structural Attitudes: The Green River coal region in Wyoming comprises two major structural basins, the Green River or Bridger basin to the west and the Great Divide-Washakie basins to the east. These basins are separated by the north-south trending Rock Springs uplift, in the core of which older, noncoal-bearing rocks are exposed. In the centers of the basins, the beds are nearly flat-lying; but around the margins of the basins, dips in places reach 20° to 50°. Around the Rock Springs anticline dips range up to 20° on the west flank and 10° on the east. Faulting is common in the area of the Rock Springs uplift and somewhat less common within the basins proper.

B. Topographic Relief: Considerable relief is present on the Rock Springs uplift, the site of most of the historic coal mining in the area. The basins themselves exhibit low to moderate relief for the most part, although this can vary greatly due to dissection.

C. Maximum Overburden: There is little directly pertinent data on the maximum amount of overburden that might be removed for surface mining in the Green River coal region. The reported strippable reserves in the region exceed 1,900 million tons and are the second largest of all coal-bearing areas in the State. Strippable deposits are generally considered to occur beneath about 150 ft or less of overburden in other areas. The coals in the Green River coal region do not reach the extreme thicknesses of the coals in some of the other areas;

nevertheless, the coals here are thick enough (up to 30 ft) that they alone or in combination may justify the stripping of thicker intervals of overburden. Underground mining, although minor in extent when compared to surface mining, will be as strong in this region as in any other part of the State. In the future, as surface-minable deposits are depleted, underground mining will become more prominent. Thus, in the long run, thick overburden should not be an overwhelming obstacle to the development of coal resources in the region. However, during the next decade, at least, coal development is likely to be limited essentially to areas where the overburden is comparably thin.

D. Market: The existing mine primarily supplies steam-electric power plants in the Pacific northwest. Mines developed in the future also may supply steam-electric power plants in the central and southern Midwest, South, and possibly the Southwest. Markets in the upper Midwest for coal from the Green River region are likely to be limited because other major fields are closer to that area and are more directly connected to it by existing railroad lines.

III. TYPICAL COAL BED CHARACTERISTICS

A. Analyses, As-Received: Twenty coal beds or groups of closely associated coal beds in the Green River coal region have been analyzed. The range and average values of representative analyses, that is, the average, typical, or median values for these analyses, are as follows:

1. Moisture: The representative moisture contents reported range from 7.5% to 23.2%, with an average of 23.2%.

2. Volatile matter: The representative volatile matter contents reported range from 29.1% to 39.1%, with an average of 32.7%.

3. Fixed carbon: The representative fixed carbon contents reported range from 31.2% to 48.1%, with an average of 40.8%.

4. Ash: The representative ash contents reported range from 2.2% to 17.1%, with an average of 8.0%.

5. Sulfur: The representative sulfur contents range from 0.41% to 5.40%, with an average of 1.37%.

6. Btu/lb: The representative heating contents, in Btu/lb, range from 7,005 to 12,476, with an average of 9,616.

Typical analyses for beds currently being mined are presented in Table 5.

B. Thickness of Coal: The average thickness of strippable coal beds ranges from 5.7 ft to 30 ft, and the maximum thickness of some beds ranges up to 50 ft.

C. Mining Problems: Underground mining in the Rock Springs uplift area has created serious subsidence problems beneath the town of Rock Springs. Data are not readily available on mining problems in other parts of the region.

HAM'S FORK COAL REGION

The Ham's Fork coal region contained an estimated 4,874.54 million tons of original, in-place coal resources, amounting to about 3.6% of the total for the State of Wyoming. This region still contains estimated, remaining strippable reserves, as of January 1, 1978, of 1,034.80 million tons, amounting to about 3.9% of the total for the State. In both of these categories, the Ham's Fork coal region ranks third of all coal-producing regions in Wyoming, after the Powder River coal basin and the Green River coal region. Of the estimated, original, in-place coal resources, 3,197.68 million tons, or 66%, are bituminous coal, and 1,676.86 million tons, or 34%, are subbituminous coal. The Ham's Fork coal region is the second largest area of bituminous coal resources in Wyoming, and includes about 24% of the total of such resources in the State.

In recent years, the annual production from the Ham's Fork coal region has been about 5 million tons, all of it from three surface mines. This has made the region the fourth largest coal-producing area in Wyoming. In the near future, two new surface mines and one small underground mine will be developed in the region.

Because of the present and anticipated predominance of surface mining in the Ham's Fork coal region, only surface mines will be considered further. There are underground-minable resources in the Ham's Fork coal region, but data on underground mines are unavailable. Consequently, generalizations about such mines cannot be established.

I. REPRESENTATIVE MINING OPERATIONS

A. Coal Rank: In the region as a whole the coal is 66% bituminous and 34% subbituminous, but only the subbituminous coal has been mined in recent years.

B. Minimum Leashold Requirement: For a minable reserve base of 20 million tons, and for an average thickness of about 4 ft per bed for surface-minable groups of multiple coal beds, the minimum leasehold required would be about 300 acres. Where thinner, individual coal beds are to be mined, the minimum leasehold required would be proportionately increased. Thicker coal beds and groups of coal beds occur in the region; however, such resources are most likely to be developed by large operations rather than by operations that are relatively small.

C. Minimum Recoverable Reserves Requirement: All of the currently proposed surface mines in this region have design capacities of between 1.0 and 4.9 million tons per year (tpy). For mine lives of from 20 to 30 years, recoverable reserves of from 20 to 150 million tons will be required. Mines smaller than 1 million tpy have been proposed for other coal-bearing areas in the State, and such mines might require less than 20 million tons of recoverable reserves. While such mines are probably possible in the Ham's Fork coal region, none has been proposed.

D. Mine Life: Probably 20 to 30 years.

E. Coal Price, FOB Mine: Recent spot market prices for subbituminous steam coal from Wyoming with less than 1% sulfur ranged from $7.25/ton for coal with 8,000 Btu/lb to $9.00/ton for coal with 9,000 Btu/lb. Prices on the regular contract market should be somewhat lower. Prices for bituminous steam coal probably are in the $18-25/ton range.

F. Design Capacity: The design capacities currently proposed for surface mines in the Ham's Fork coal region range from 1.5 to 4.0 million tpy.

G. Mining Technology: Existing mines use standard surface-mining technology centered around draglines, shovels, and dozers.

H. Capital Requirements: $15 to $20 million (±20%) for a surface mine producing 1 million tpy.

I. Labor Requirements: For the surface mines currently producing in the Ham's Fork coal region, the number of employees per million tons of coal produced annually ranges from 83.5 to 114.6. These ratios are among the highest in the State.

J. Surface Equipment: The mines in the Ham's Fork coal region should require standard surface-mining equipment including draglines, dozers, front-end loaders, shovels for stripping and loading, and trucks. Additionally, other common equipment and facilities will include haul roads and railroad lines, conveyors, coal storage and loading facilities, offices, and support facilities.

K. Proximity to Transportation: The Ham's Fork coal region is served by two main lines of the Union Pacific Railroad. Most of the region is within about 25 miles of these lines.

L. Common Transportation Mode: Coal is transported from existing mines by conveyors and trucks to nearby electric power plants or to railroad facilities from which the coal is shipped.

M. Community Infrastructure Requirements: There are some small towns in the area that might supply some trained manpower to the proposed mines; however, most of the available, trained labor force is probably occupied with existing operations, and development of new mines will probably require population growth in the region.

II. GENERAL MINING CONDITIONS

A. Structural Attitudes: The Ham's Fork coal region is structurally the most complex of all of the coal-bearing areas of Wyoming. It is the only area in the State that falls within the Overthrust Belt. In this area folded Paleozoic and Mesozoic rocks have been thrust eastward over folded younger Cretaceous rocks. Later Cretaceous and Tertiary rocks rest unconformably on the older rocks. The coal-bearing formations of Cretaceous and Tertiary ages generally occur in synclines and crop out in long, narrow belts. The coal fields are bound structurally by the major faults and eroded limbs of folds, and physiographically by the major mountain ranges that are formed by the faults and folds. In most of the fields, the beds dip to the west typically 25° to 30°, but dips range as low as 16° and as high as 80°. In one major coal field, the coal beds dip to the east at 10° to 20°. Thrust faults and high-angle faults are common in the region.

B. Topographic Relief: This is a region of considerable topographic relief and relatively high elevations in the coal-bearing areas, which may create severe access problems in some instances.

C. Maximum Overburden: Because of the steep dips in this region, the overburden on coal beds increases rapidly with distance from the outcrop. The bulk of the coal resources of this area lie beneath greater thicknesses of overburden than would typically be removed for surface mining in other areas of the State. However, overburden thickness does not pose an insurmountable obstacle to intensive surface mining. For example, by using dip-slope mining techniques and by mining several coal beds, the Kemmerer Coal Company plans to excavate one pit to a depth of 1,005 ft, and is studying the possibility of ultimately expanding this pit to a depth of 1,770 ft. Despite the great depth of this pit, the stripping-ratio is held constant at about 4:1.

D. Market: Future markets for this coal will probably be greatest in the West. The coal is currently used mostly in steam-electric power plants, but it is also supplied to various industries.

III. TYPICAL COAL BED CHARACTERISTICS

A. Analyses, As-Received: Coal from 10 beds or closely related groups of beds in the Ham's Fork coal region have been analyzed. The range and average values of the representative average or typical values for the analyses of these beds are as follows:

1. Moisture: The representative moisture contents reported ranged from 3.0% to 21.2%, with an average of 9.1%.

2. Volatile matter: The representative contents reported ranged from 33.9% to 39.6%, with an average of 37.4%.

3. Fixed carbon. The representative fixed carbon contents reported ranged from 41.3% to 52.4%, with an average of 47.4%.

4. Ash: The representative ash contents ranged from 3.0% to 8.8%, with an average of 6.1%.

5. Sulfur: The representative sulfur contents ranged from 0.2% to 1.1%, with an average of 0.7%.

6. Btu/lb: The representative heating values ranged from 9,520 Btu/lb to 12,930 Btu/lb, with an average value of 11,796 Btu/lb.

B. Thickness of Coal: The average thickness of groups of currently mined beds is between 40 ft and 45 ft. The range of thickness of individual mined and minable beds is 5 ft to 110 ft.

C. Mining Problems: The steep dips of the coal beds in much of this relatively rugged area create special mining problems that usually can be overcome by the skilled operator.

HANNA COAL FIELD

The Hanna coal field contained an estimated 3,916.96 million tons of original, in-place coal resources, amounting to about 2.9% of the total for the State of Wyoming. This field still contains estimated, remaining strippable reserves, as of January 1, 1978, of 326.9 million tons, amounting to about 1.2% of the total for the State. In both of these categories, the Hanna coal field ranks fourth of all coal-bearing areas in Wyoming. Of the resources in the field, over 98% are subbituminous coal, and the remainder are bituminous coal.

Despite the small amounts of resources and reserves in the Hanna coal field, compared to other parts of the State, this area deserves particular attention. In 1979 it was the second most productive area in Wyoming, accounting for about 14% of the total production of the State, and it is also currently the second most active coal-producing area, in terms of the number of mines. In the coming decade, the Hanna coal field should fall behind the Green River coal region in these categories. However, the field is expected to remain the third most productive and active coal-producing area in the State.

As in other areas of Wyoming, surface mining in this field will predominate over underground mining, both in terms of total production and number of mines. However, in the Hanna coal field, underground mining will contribute proportionally more in both of these categories than in any other part of the State. Despite the comparative prominence of underground mining in this area, there are few general data available on it, and only surface mines will be discussed in detail under Representative Mining Operations.

I. REPRESENTATIVE MINING OPERATIONS

A. Coal Rank: The coal in the Hanna coal field is virtually all subbituminous, with a very small amount of bituminous coal.

B. Minimum Leasehold Requirement: For surface mines with minable reserves of about 20 million tons, with a recovery factor of 85%, for an average thickness of strippable beds of from 10 ft to 20 ft, the minimum leasehold required would be several hundred acres. A similar minable reserve base may be appropriate for underground mines in this area. However, for these mines, because the recovery factor may only be about 50%, the minimum leaseholds required would be proportionately larger. The Hanna No. 1 and No. 2 coal beds are the thickest mined beds in this area, but they reach thicknesses of only 30 ft to 36 ft. Thus, even where these beds might be mined, the minimum leasehold required would not be substantially reduced.

C. Minimum Recoverable Reserves Requirement: 20 to 30 million tons for both surface and underground mines.

D. Mine Life: 20 to 30 years.

E. Coal Price, FOB Mine: Recent spot market prices for steam coal from Wyoming with less than 1% sulfur ranged from $7.25/ton for coal with 8,000 Btu/lb to $9.00/ton for coal with 9,000 Btu/lb. Prices on the regular contract market should be somewhat less.

F. Design Capacity. The design capacities of currently ongoing and proposed surface mines in the Hanna basin range from 1.3 to 3.0 million tons per year (tpy). For underground mines, the capacities range from 0.9 to 1.5 million tpy. One proposed combined surface and underground mine will have a capacity of 3.5 million tpy.

G. Mining Technology: Surface mines will probably use standard surface mining technology comparable to that used in other areas of the State. Data are not available for underground mines, but these mines should be large enough to justify the use of longwall mining equipment.

H. Capital Requirements: About \$15 to \$20 million (±20%) is required for a surface mine of 1 million tpy capacity; \$35 to \$40 million (±20%) is required for an underground mine of similar capacity.

I. Labor Requirements: For current surface mines in the Hanna coal field the values of the ratios of employees per million tons of coal produced annually range from 70.2 to 152.5. The average value for this area, 94.4, is only slightly lower than the average value for the Ham's Fork coal region, which is the highest in the State, and is more than twice the average value for the Powder River coal basin, which is the lowest in the State. Underground mines of the capacities proposed will probably require 250 to 350 employees. Data are not generally available, but these values appear to be typical for the State.

J. Surface Equipment: Surface mines will require standard surface-mining equipment, including draglines, shovels, dozers, front-end loaders, and trucks, as well as support facilities such as haul roads and railroad lines, coal storage and loading facilities, and offices. At least some of these support facilities will be needed by the underground mines.

K. Proximity to Transportation: A main line of the Union Pacific Railroad passes near the southern edge of the Hanna coal field. All of the field is within about 25 miles of this line, and at least some of the existing mines are served by branches of it.

L. Common Transportation Mode: Coal will probably be transported by both conveyors and trucks to railroad facilities for shipment on unit trains.

M. Community Infrastructure Requirements: There area a few small towns around the Hanna coal field, and these may support some trained personnel associated with past and present operations. This is one of the few areas in Wyoming where some current operations will shut down over the coming decade, and the employees released from these mines may be able to fulfill a substantial part of the manpower needs of the new and expanding mines.

II. GENERAL MINING CONDITIONS

A. Structural Attitudes: The Hanna coal field lies in a larger, intermontane syncline that has been subdivided into two basins by a smaller northeast-southeast trending anticline. To the northwest is the Hanna basin, and to the southeast is the Carbon basin. Detailed data on the structural geology of this field are not available. However, the beds in the center of the basin tend to be relatively flat-lying, whereas dips probably increase somewhat around the margins of the basin and along the flanks of the central anticline. Faults are common in the field.

B. Topographic Relief: The Hanna basin varies in relief from relatively flat-lying and rolling to fairly rugged and dissected. However, access to the area presents no great problem.

C. Maximum Overburden: Data are unavailable on the overburden in this area and on its relationship to mining. About 8% of the region's total coal resources are considered strippable reserves, and these are generally found in areas with less than about 150 ft of overburden. Individual coal beds are probably not thick enough to currently justify mining in areas of much thicker overburden, although some of the coal-bearing sequences contain numerous coal beds that in aggregate might justify mining in areas of thick overburden. To a greater degree in this area than in any other area of the State, the problems of thick overburden for surface mining have been circumvented by mining underground instead.

D. Market: Because of the location of this field within the State and its relationship to railroad lines, the largest potential market for its coal will probably be in the Midwest.

III. TYPICAL COAL BED CHARACTERISTICS

A. Analyses, As-Received: Fourteen major coal beds in the Hanna coal field have been analyzed. The range and average values of the representative average, typical, single, or median analyses for these beds are as follows:

1. Moisture content: The representative moisture contents reported range from 9.5% to 36.9%, with an average value of 13.5%.

2. Volatile matter: The representative volatile matter contents reported range from 33.6% to 40.9%, with an average of 37%.

3. Fixed carbon: The representative fixed carbon contents reported range from 37.9% to 47.7%, with an average of 43.9%.

4. Ash: The representative ash contents reported range from 5.5% to 14.7%, with an average of 8.0%.

5. Sulfur: The representative sulfur contents reported range from 0.35% to 0.90%, with an average of 0.56%.

6. Btu/lb: The representative heating values reported range from 9,327 Btu/lb to 11,350 Btu/lb, with an average of 10,527 Btu/lb.

B. Thickness of Coal: The average thickness of strippable beds ranges from about 10 ft to 21 ft. Numerous beds are thinner, and at least two beds achieve thicknesses of from 30 ft to 36 ft.

C. Mining Problems: No data are readily available, but no unusual problems are anticipated.

POWDER RIVER COAL BASIN

The Powder River coal basin contains more than 80% of the known coal resources of the State of Wyoming. This is almost seven times the amount of known resources in Wyoming's next richest coal-bearing area, the Green River coal region. The Powder River coal basin has been divided into 12 fields and includes eight major, named strippable deposits. In 1977, the Powder River coal basin was the site of seven of Wyoming's 16 surface mines, and this basin accounted for over half of the total coal production of the State. The Powder River coal basin is also the site of more than half of the State's proposed new or expanded mines and over 70% of the proposed new or expanded mines that will have capacities of more than 5 million tons per year (tpy) (Table 2).

All current and proposed mines in the Powder River basin are surface mines. Underground coal resources do exist in this area. However, because of the prevalence of surface mining and the abundance of strippable reserves, only surface mines will be considered under representative mining operations.

I. REPRESENTATIVE MINING OPERATIONS

A. Coal Rank: Virtually all of the coal is subbituminous, except for a small area of lignite in northeastern Campbell County.

B. Minimum Leasehold Requirement: For a minable reserve base of 20 million tons, which is probably near the minimum that would be developed in view of typical annual production rates and mine lives, and for bed thicknesses of from 50 to 100 ft, which are typical of the beds being mined in the basin, the minimum leasehold requirement could be as small as a few hundred acres. Thicker beds are present in the area that possibly could be mined on even smaller leaseholds. However, the trends, even for areas of thick coal beds, are toward more areally extensive mines with much larger than the minimum production rates. Some proposed mines, for example, would have annual production capacities of more than 20 million tpy, and would require leaseholds of thousands of acres.

C. Minimum Recoverable Reserves Requirement: The smallest currently proposed surface mine in the Powder River coal basin would have an annual production rate of only about 24,000 tons, and one other would have rates of less than 1 million tpy. Such mines would require total recoverable reserves of from less than 1 million tons up to several million tons or more. However, these mines are not representative of the overall trend of mines developing in the basin. Minable reserves of from 20 to 30 million tons are probably the minimum necessary for the development of mines with annual capacities of about 1 million tons. Even these mines will be small producers compared to the projected basin-wide average annual production of over 9 million tons. More typical new mines will require well over 100 million tons of recoverable reserves.

D. Mine Life: For typical mines the life will probably be 20 to 30 years. Some very small mines, with smaller investments in capital, may be able to operate economically for shorter time periods.

E. Coal Price, FOB Mine: Recent spot market prices for steam coal from Wyoming with less than 1% sulfur were $7.25/ton for coal of 8,000 Btu/lb, $8.00/ton for coal of 8,500 Btu/lb, and $9.00/ton for coal of 9,000 Btu/lb. Prices on the regular contract market should be somewhat lower.

F. Design Capacity: The projected design capacities of currently proposed new or expanded mines in the Powder River coal basin range from 24,000 tpy to 33,000,000 tpy. Of these mines, two will have capacities of less than 1 million tpy, six will have capacities of 1 to 4.9 million tpy, five will have capacities of 5.0 to 9.9 million tpy, 10 will have capacities of 10.0 to 14.9 million tpy, two will have capacities of 15.0 to 19.9 million tpy, and two will have capacities of 20 million tpy or more. The Powder River coal basin is the only area in

Wyoming for which mines with capacities of 10 million tpy or more have been proposed, and this area is the site of most of the proposed mines with capacities of 5.0 to 9.9 million tpy (Table 2).

G. Mining Technology: Existing mines use standard surface-mining technology centered around draglines, shovels, and bucketwheel excavators.

H. Capital Requirements: $15 to $20 million (±20%) for a surface mine producing at a rate of 1 million tpy.

I. Labor Requirements: Labor requirements for surface coal mines in the Powder River coal basin have been generally the lowest of the major producing regions of Wyoming. Data for 1977 from the five mines in the basin that were producing at a substantial proportion of design capacity show ratios of employees per million tons of coal produced that range from 25.5 to 55.1. These ratios comprise five of the six lowest in the State. They include the lowest ratio, which is for the largest mine in the State at that time, Amax Coal's Belle Ayr mine, which produced over 13 million tons of coal in 1977. The other mines, however, span the range of rates of production that were typical of the State as a whole that year. In the future, as large mines are developed and the potential for economies of scale is exploited, mines in the Powder River coal basin should maintain relatively low requirements for labor.

J. Surface Equipment: The mines in the Powder River coal basin should require standard surface mining equipment, including loading and stripping shovels, draglines, bucketwheel excavators, dozers, front-end loaders, trucks, and so on. In addition these mines will typically require haul roads and railroad spurs, conveyors, coal storage and loading facilities, support facilities, and offices.

K. Proximity to Transportation: The Powder River coal basin is served by two main lines of the Burlington Northern Railroad, one of which has several spurs to existing mines, and by a main line of the Chicago and Northwestern Railroad. Much of the region is within 25 miles of existing rail lines, but most of the areas of currently proposed developments are much closer to existing or proposed lines. The area is also served by numerous State and Federal highways.

L. Common Transportation Mode: Coal is transported from the mines by conveyors and trucks to railroad facilities for shipment on unit trains.

M. Community Infrastructure Requirements: There are several small communities in and around the Powder River coal basin that may be a source of trained personnel for future development. However, much of this work force probably already is currently employed in the existing coal mining operations. There are several existing and proposed electric power plants in the area that could readily supply electricity to the proposed mines.

II. GENERAL MINING CONDITIONS

A. Structural Attitudes: The Powder River coal basin is structurally the simplest coal-bearing area in Wyoming. The basin is a broad, asymmetric syncline that extends northward into Montana. The axis of the syncline is west of the center of the basin, and beds in the eastern and central parts of the basin are nearly flat lying. Around the margins of the basin, the dips steepen somewhat, with the Tertiary beds dipping at 2° to 3° and the underlying Cretaceous beds dipping slightly more. The steepest dips are found on the west flank of the basin where at least the Paleocene rocks have been tilted to angles of 10° to 25°. Faults are relatively uncommon in the basin as a whole, but they are comparatively common on the west flank. Most faults trend northeast-southwest. The maximum vertical displacements reach 300 to 400 ft in the Sussex area.

B. Topographic Relief: The Powder River basin consists, for the most part, of rolling, dissected but relatively low-relief, topography which presents no major problems for coal mining operations.

C. Maximum Overburden: The main coal-bearing units, the Paleocene Fort Union Formation and the Eocene Wasatch Formation, crop out extensively in the eastern and central parts of the basin. Strippable deposits occur in the east-central and western parts of the basin. The known strippable deposits, which include about 20% of the estimated total resources of the area, are generally found beneath less than about 150 ft of overburden. There are numerous beds under greater thicknesses of overburden; some of these beds are so thick, either singly or in combination, that their stripping ratios may be favorable for mining in areas of thicker overburden.

D. Market: Coal mines in the Powder River basin is used both in Wyoming and shipped throughout the Midwest.

III. TYPICAL COAL BED CHARACTERISTICS

A. Analyses, As-Received: The coal from the Powder River coal basin has been widely analyzed, and most of the major, minable beds have been sampled. The values reported below reflect the low, high, and mean values for 11 to 15 analyzed beds.

1. Moisture: The low values reported range from 20.3% to 34.9%, with an average low value of 29.2%. The high values reported range from 32.6% to 44.0%, with an average high value of 38.1%. The typical or mean values reported range from 30.5% to 41.7%, with an average typical value of 34.7%.

2. Volatile matter: The low values reported range from 26.5% to 34.4%, with an average low value of 29.8%. The high values reported range from 31.9% to 49.3%, with an average low value of 37.0%. The typical or mean values reported range from 28.7% to 37.5%, with an average typical value of 32.9%.

3. Fixed carbon: The low values reported range from 20.3% to 34.9%, with an average of 29.2%. The high values reported range from 32.6% to 44.0%,

with an average high value of 38.1%. The typical or mean values reported range from 30.5% to 41.7%, with an average typical value of 34.7%.

4. Ash: The low values reported range from 2.3% to 8.8%, with an average of 4.7%. The high values reported range from 6.6% to 22.1%, with an average high value of 11.8%. The typical or mean values reported range from 4.3% to 11.4%, with an average typical value of 6.5%.

5. Sulfur: The low values reported range from 0.14% to 0.74%, with an average low value of 0.37%. The high values reported range from 0.50% to 3.26%, with an average high value of 1.44%. The typical or mean values reported range from 0.34% to 1.50%, with an average typical value of 0.63%.

6. Btu/lb: The low values reported range from 6,480 to 9,220, with an average low value of 7,749. The high values reported range from 8,270 to 10,410, with an average high value of 9,001. The typical or mean values reported range from 7,884 to 9,710, with average typical values of 8,449.

The typical values and range of values of moisture, ash, sulfur, and heating values of beds currently mined in the Powder River coal basin are shown in Table 5.

B. Thickness of Coal: The Powder River coal basin includes at least 16 coal beds whose typical thicknesses range between 10 and 30 ft, and several of these beds have maximum thicknesses of 50 ft or more. The thickest coal beds are the Healy bed, in the Eocene Wasatch Formation, which averages 163 ft in thickness and reaches a maximum thickness of about 220 ft, and the Wyodak-Anderson bed, in the Fort Union Formation, which averages 70 ft in thickness and reaches a maximum thickness of about 125 ft.

C. Mining Problems: Apart from some problems with burned ("clinker") coal beds in parts of the basin, and some water in those coal beds that behave like aquifers, no serious problems are known that pertain to the surface mining of coal in the region.

OTHER COAL FIELDS

Other coal-bearing areas in Wyoming include the Wind River coal basin, Bighorn coal basin, Rock Creek coal field, Jackson Hole coal field, Black Hills coal region, and Goshen Hole coal field. These areas together, excluding the Goshen Hole coal field, contained about 0.4% of the State's estimated, original, in-place resources of bituminous coal and about 1.5% of the State's estimated, original in-place resources of subbituminoius coal. No estimates of resources have been made for the Goshen Hole coal field, but no beds thicker than 2.5 ft are known in that area. It should be pointed out that, although these areas account for a minute proportion of the resources currently estimated, the estimates reflect only mapped and explored areas. When these fields are better known, especially the larger Bighorn and Wind River coal basins, it may be that their share of the State's estimated resources will increase considerably.

The Bighorn coal basin is the largest of the six coal-bearing areas listed above. In fact, areally it is the third largest coal-bearing region in Wyoming. It is also the only area, other than the four areas discussed separately in detail, that is considered to have strippable deposits of subbituminous coal and minable deposits of bituminous coal, although these are very small in comparison to similar deposits elsewhere in the State. Of the six minor coal-bearing areas under discussion here, this is the only one in which there is an operating mine. This is a surface mine that is presently producing less than 50,000 tons per year (tpy), and, although its expansion is planned, its design capacity is less than 1 million tpy. Historically, mining has been concentrated around the margins of the basin, where the coal-bearing formations are exposed. These areas, however, are also the areas of greatest structural complexity in the basin. Beds commonly dip 15 to 50 degrees on the flanks of local folds, and normal faults are common. Coal occurs in four formations, ranging from the Upper Cretaceous Mesaverde Formation to the Paleocene Polecat Bench Formation. Several coal beds are

4 ft to 12 ft thick, and one bed is up to 38 ft thick. The potential for surface mining in this area may be reduced by the limited and structurally complicated occurrences of coal. Conventional underground mining has been done here in the past, and in the future it may become feasible again.

The Wind River coal basin is similar to the Bighorn coal basin in that it is a large, asymmetric syncline with coal-bearing formations exposed along its margins but deeply buried in its center. All of the coals in the Wind River coal basin are believed to be subbituminous in rank, at least in the marginal areas of the basin. Unpublished data indicate that there are three surface mines proposed for this basin, but the only one for which a design capacity has been set will produce less than 50,000 tpy.

Little data are available about the four smallest coal-bearing areas of the State. The Jackson Hole and Rock Creek coal fields are believed to contain minable resources. The Black Hills coal region once contained a small amount of bituminous coal, but is now generally considered to be "mined out". Only thin coals are known in the Goshen Hole coal field.